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Harm caused by Marine Litter

MSFD GES TG Marine Litter – Thematic Report

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Foreword

The Marine Directors of the European Union (EU), Acceding Countries, Candidate Countries and EFTA Countries have jointly developed a common strategy for supporting the implementation of the Directive 2008/56/EC, “the Marine Strategy Framework Directive” (MSFD). The main aim of this strategy is to allow a coherent and harmonious implementation of the Directive. Focus is on methodological questions related to a common understanding of the technical and scientific implications of the Marine Strategy Framework Directive. In particular, one of the objectives of the strategy is the development of non-legally binding and practical documents, such as this report, on various technical issues of the Directive.

The MSFD Technical Group on Marine Litter TG ML acts through a mandate by the European Marine Directors. It is led by DG ENV and chaired by IFREMER, the EC Joint Research Centre (JRC) and the German Federal Environment Agency (UBA). TG ML Members include EU Member State delegates, Regional Sea Conventions, additional stakeholders and invited technical experts. The TG ML provides advice to the MSFD implementation process, it reviews scientific developments and prepares technical guidance and information documents.

This present technical report is part of a series of thematic reports issued by the TG ML providing guidance on specific topics: ***Harm caused by Marine Litter*****,** *Identifying Sources of Marine Litter* and *Riverine Litter Monitoring – Options and Recommendations.* These thematic reports are targeted to those experts who are directly or indirectly implementing the MSFD in the marine regions.

This technical report should further support EU Member States in the implementation of monitoring programmes and plans of measures to act upon marine litter.

The members of the Marine Strategy Coordination Group will assess and decide upon the necessity for reviewing this document in the light of scientific and technical progress and experiences gained in implementing the Marine Strategy Framework Directive.

Disclaimer:

This document has been developed through a collaborative programme involving the European Commission, all EU Member States, Accession Countries, and Norway, international organisations, including the Regional Sea Conventions and other stakeholders and Non-Governmental Organisations. The document should be regarded as presenting an informal consensus position on best practice agreed by all partners. However, the document does not necessarily represent the official, formal position of any of the partners. Hence, the views expressed in the document do not necessarily represent the views of the European Commission.

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Abstract

Marine litter is a global concern with a range of problems associated to it, as recognised by the Marine Strategy Framework Directive (MSFD). Marine litter can impact organisms at different levels of biological organization and habitats in a number of ways namely: through entanglement in, or ingestion of, litter items by individuals, resulting in death and/or severe suffering; through chemical and microbial transfer; as a vector for transport of biota and by altering or modifying assemblages of species. Marine litter is a threat not only to marine species and ecosystems but also carries a risk to human health and has significant implications to human welfare, impacting negatively vital economic sectors such as tourism, fisheries, aquaculture or energy supply and bringing economic losses to individuals, enterprises and communities.

This technical report aims to provide clear insight about the major negative impacts from marine litter by describing the mechanisms of harm. Further it provides reflexions about the evidence for harm from marine litter to biota comprising the underlying aspect of animal welfare while also considering the socioeconomic effects, including the influence of marine litter on ecosystem services.

General conclusions highlight that understanding the risks and uncertainties with regard to the harm caused by marine litter is closely associated with the precautionary principle. The collected evidence in this report can be regarded as a supporting step to define harm and to provide an evidence base for the various actions needed to be implemented by decision-makers. This improved knowledge about the scale of the harmful effects of marine litter will further support EU Member States (MSs) and Regional Seas Conventions (RSCs) to implement their programme of measures, regional action plans and assessments.

1. Introduction

Marine litter (or debris, both expressions are used synonymous in this report), and in particular the accumulation of plastic litter in the marine environment, has been identified as a major global problem alongside other key environmental issues of our time (Sutherland et al., 2010; G7 Leader´s declaration 2015). Marine litter can be transported by ocean currents over long distances from its origin and is found in all marine environments, even in remote areas such as uninhabited islands in the open oceans or deep sea.

Marine litter is usually defined as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment. Records of the most common items found in surveys and clean-ups show that marine litter is dominated by plastic items both in shallow and deeper waters. The top ten debris items recorded by the 2013 International Coastal Cleanup were, in descending order: cigarette butts, plastic food wrappers, plastic beverage bottles, plastic bottle caps, straws and stirrers, plastic grocery bags, glass beverage bottles, other plastic bags, paper bags and beverage cans. Seven of these items are made of plastics (CBD, 2016).

In order to achieve Good Environmental Status (GES) Descriptor 10 of the Marine Strategy Framework Directive (MSFD) calls EU Member States (MS) to achieve a status where "marine litter does not cause harm to the coastal and marine environment." Building upon this definition according to the MSFD GES Technical Group on Marine Litter (TG ML, 2013), GES is achieved, when:

1. Litter and its degradation products present in, and entering into EU waters do not cause harm to marine life and damage to marine habitats;
2. Litter and its degradation products present in, and entering into EU waters do not pose direct or indirect risks to human health;
3. Litter and its degradation products present in, and entering into EU waters do not lead to negative socioeconomic impacts.

There is a range of problems associated with marine litter, making it a complex multidisciplinary problem. The MSFD Task Group 10 (Galgani et al., 2010) has set the basis for the further work of the MSFD TG ML and divided "harm" from marine litter into three general categories:

- Social for example reduction in aesthetic value and public safety,
- Economic such as cost to tourism, damage to vessels, fishing gear and facilities, losses to fishery operations, cleaning costs and
- Ecological including mortality or sublethal effects on plants and animals through entanglement, capture and entanglement from ghost nets, physical damage, smothering and ingestion including uptake of micro-particles (mainly microplastics) and the influence from chemicals as well as creation of transfer pathways, facilitating the invasion of alien species, altering benthic community structure.

The key aim of this report is to provide an overview in order to establish a clear understanding about the severity and scale of the harmful effects of marine litter in order to assist EU Member States (MSs) and Regional Seas Conventions (RSCs) in upcoming assessments, decision-making and implementation of measures. Among these activities are the next MSFD Assessment Cycle starting in 2018, the OSPAR Intermediate Assessment 2017, the HELCOM HOLAS II 2017 and the Regional Action Plans on Marine Litter in the North-East Atlantic, the Baltic and the Mediterranean Sea.

This report evaluates the above mentioned and some additional important impacts from marine litter by describing the mechanisms of and providing evidence for harm. Based on currently available information, the report seeks to quantify the impacts from marine litter in terms of significance and extent. Impacts on biota and habitats are further explored in chapter 2, social and economic harm are treated in chapter 3, including considerations on the influence of marine litter on ecosystems services. Chapter 4 explores on possible approaches to carry out risks assessments for marine litter. Furthermore it provides guidance how risk assessments might be used for the management of marine litter by decision makers. Conclusions from the impact sections, responding to the basic questions: "Is there harm? What is the evidence for the extent of harm?” are compiled in a dedicated chapter 5. Due to their nature, impacts are often difficult to quantify at large scales and the outcomes of research efforts, about which this report provides an overview, will need to be considered as further information on both harm and the distribution and abundance of litter types becomes available.

2. Harm to biota

2.1 Types of harm

It is well established that marine litter and in particular plastics affect marine organisms and habitats. Marine litter impacts organisms at different levels of biological organization and habitats in a number of ways, namely through entanglement in, or ingestion of, litter items by individuals, through chemical transfer, as a vector for transport of biota and by altering or modifying assemblages of species e.g. by providing artificial habitats or through smothering. Impacts vary depending on the type and size of the marine litter items and the organisms that encounter it (CBD, 2012). Each year, millions of animals that live in the oceans are debilitated, mutilated and killed by marine litter (Butterworth et al., 2012).

Marine litter has been demonstrated to have deleterious impact on individuals, with direct lethal or sublethal effects. It seems inevitable that entanglement and ingestion by/of marine debris will alter the biological and ecological performance of individuals, compromising an individual's ability to capture food, digest food, sense hunger, escape from predators, and reproduce—as well as decreasing body condition and compromising locomotion, including migration (CBD 2012). Ingestion of litter, and in particular microplastic particles, can provide a pathway facilitating the transport of harmful chemicals to organisms. Experimental studies have shown that phthalates and BPA affect reproduction in all study species and generally induce genetic aberrations (Oehlmann et al., 2009). However, the extent to which plastic debris is important in the transfer of chemicals to biota in the natural environment is not certain.

A recent assessment of the number of marine species affected by marine litter (CBD, 2016) revealed that a further 154 new species are affected since the last review in 2012 (CBD, 2012), bringing the total number of impacted species to 817, which represents a 23 per cent increase. Restricting the assessment to ingestion and entanglement records for marine and coastal species revealed that a further 136 species are known to be affected, bringing the total number of affected species 519. The main bulk of new species records were for the ingestion of plastics, including microplastics, and entanglement in lost or abandoned fishing gear (predominantly line, nets or pots). Many of the affected species are protected. For example of the 120 marine mammals species listed on the IUCN Red List of Threatened Species (IUCN, 2014), 54 (45 %) were reported to have interacted (ingestion and/or entanglement) with marine litter. About 15% of the marine mammal species affected through entanglement and ingestion are on the IUCN Red List. Cross-referencing only the 154 new records of affected species with the IUCN Red List indicated that approximately 10 per cent are threatened, vulnerable, endangered or critically endangered, including large baleen whales and geographically restricted sea birds species. In addition, a further nine species of affected cetacean were identified as either not assessed by the Red List to date or were data deficient, including five species of toothed whales.

It is highly likely that there are substantially more marine species affected by marine litter, either directly or indirectly, given the ubiquitous presence of litter items, such as persistent microplastics in the marine environment (CBD, 2016). The fragmentation of plastic litter can be caused by abiotic factors as well as through biological processes (Kühn et al., 2015). Incidences of microplastics ingestion are of particular concern since they are widely distributed and of small sizes, hence a wide range of organisms may ingest them. The smaller the particle the greater is the availability to small animals, which are of special concern, since they form the base of the food web. Deposit- and filter feeding marine fauna will be especially susceptible to the uptake or ingestion of microplastics, as well as planktonic invertebrates in oceanic gyre regions where microplastics concentrations are high (CBD, 2016). The UNEP yearbook 2011 identified marine microplastics to be one of the main global emerging environmental issues.

In this chapter 2 we present the major biological impacts, provide case studies for relevant species for the two main types of impacts namely entanglement and ingestion and discuss the different levels of biological organization affected. These findings mainly present and discuss numerical data on how many animals are affected and if these numbers have relevance at a population level, but we also look into the severity of suffering and therefore introduce the issue of animal welfare. The evidence provided within this report shows the large-scale and serious threat that marine litter poses to the welfare of wild marine animals.

2.2 Entanglement

2.2.1 Scale and extent of entanglement in marine wildlife

The most visible effect of pollution on marine organisms is entanglement of wildlife in marine litter, often in discarded or lost fishing gear or rope. Direct harm is in general, more frequently reported for entanglement than for ingestion, since negative effects on individuals are more obvious to detect, with external injuries and death often observed. Direct harm or death is reported in 80% of reports of entanglement and in only 5% of ingestion reports (CMS, 2014).

The data should be interpreted with caution as they are likely to be biased by differences in the frequency of reporting, since entanglement is much more visible and therefore more often recorded in comparison to ingestion, which requires a *post mortem* examination to confirm (CBD, 2012). However, from species records it becomes clear that the problem is of a substantial nature. Kühn et al. (2015) found in comparison to the comprehensive review by Laist (1997) the number of bird, turtle and mammal species with known entanglement reports increased from 89 (21%) to 161 (30%), thereunder 100% of marine turtles (7 of 7 species), 67% of seals (22 of 33 species), 31% of whales (25 of 80 species) and 25% of seabirds (103 of 406 species) with substantial increases in species records for fishes (89 species) and invertebrates (92 species). Baleen whales (69%; 9 of 13 species) and eared seals (100%, 13 of 13 species) appear to be the mammals most affected by entanglement.

Table 1: Number of species with records of entanglement documented in relation to the number of species known (adapted from Kühn et al., 2015)

Species Group	Number of known species	Number of species with recorded entanglement (Kühn et al., 2015)	Comments
Marine mammals total	123	51 (41.5%)	Baleen whales 69%, toothed whales 25%, phocid seals 47%, eared seals 100%)
Fish	32 554	89	Too little sampling for %
Seabirds	406	103 (25.4%)	
Marine turtles	7	7 (100%)	
Sea snakes	62	2 (3.2%)	

Although studies reporting the entrapment or entanglement of fish species in derelict fishing gear has substantially increased the number of species reported (see table 1), for reptiles, fish and invertebrates the percentage of affected species is not a useful statistic because there are many thousands of species which have not been properly investigated. For instance it may be considered less worthwhile to publish individual entanglement records for common fishes or inconspicuous small species than, for example, for a larger megafauna (Kühn et al., 2015). Findings indicate that worldwide between 57 000 and 135 000 pinnipeds and baleen whales are entangled each year, in addition to the inestimable – but likely millions – of birds, turtles, fish and other species. In general estimates for animal entanglement and ingestion rely on animals seen alive (or recently deceased) and so are likely to seriously underestimate the problem. If animals are affected but die unseen, then they are not reported. Evidence suggests that only 3 to 10% of entanglements are witnessed and reported (Butterworth et al., 2012).

In table 2 the frequency of entanglement for selected species is provided, listing the percentage of individuals with recorded entanglement.

Table 2: Frequency of entanglement for selected species

Species	Size of sample	% of individuals with recorded entanglement	Geography	Sources
Leach's Storm Petrel	151	11%	Equatorial Pacific	Ainley et al., 1990
White-faced Storm Petrel	13	6.9%	Equatorial Pacific	Ainley et al., 1990
Brown Pelican	557	63%	California	Dau et al., 2009
Northern Gannet (dead)	28	29%	North Sea Helgoland	Vauk and Schrey 1987
Northern Gannet (fly off cliff)	313	2.6%	North Sea Helgoland	Vauk and Schrey 1987
Northern Gannet (entangled in nest)	656 684	2.6% (2014) 3.5% (2015)	North Sea, Helgoland	Schulz et al. (in publication)
Northern Fulmar	67	1.8%	North Sea, Helgoland	Schulz et al. (in publication)
Guillemot	2880 3381	1.1 (2014) 1.0 (2015)	North Sea, Helgoland	Schulz et al. (in publication)
Grey Seal	58	3.6-5%	Cornwall, UK	Allen et al., 2012
Common minke whale	11	9.1%	UK	Deaville et al., 2010
California/Galapagos/Japanese Sea Lion	3574	3.7%	California, USA	Goldstein et al., 1999
Guadalupe fur seal	13	15.4	California, USA	Goldstein et al., 1999
Harbour seal	1072	1.2	California, USA	Goldstein et al., 1999
Northern Elephant seal	1484	0.4	California, USA	Goldstein et al., 1999
Common Bottlenose dolphin	302	3.9%	South Carolina, USA	McFee et al., 2006

Species	Size of sample	% of individuals with recorded entanglement	Geography	Sources
Green turtle	5347	9%	Florida, USA	Adimey et al., 2014
Loggerhead Turtle	9950	4.2%	Florida, USA	Adimey et a.,l 2014
Leatherback turtle	304	14.1%	Florida, USA	Adimey et al., 2014
Hawksbill turtle	362	8.3%	Florida, USA	Adimey et al., 2014
Kemp's Ridley Turtle	1346	5.1%	Florida, USA	Adimey et al., 2014
Olive Ridley turtle	3	33.3%	Florida, USA	Adimey et al., 2014
Loggerhead turtle (live)	948	4.6%	Italy	Cassale et al., 2010
Loggerhead turtle (dead)	307	6.6%	Italy	Cassale et al., 2010

2.2.2 Lethal and chronic (long-term) impacts

If entanglement is acute, it causes an immediate and severe welfare problem. For example if a marine mammal is prevented from resurfacing because of entanglement or entrapment, it will asphyxiate and drown. This process can take minutes to hours. Asphyxiation can also be caused by ligatures around the neck or occlusion in the blowhole of whales (Cassoff et al., 2011). Severance of the carotid artery by ingrown ligatures is known particularly for seals (Delong et al., 1990) and haemorrhaging and debilitation due to severe damage to tissues including laceration of large blood vessels were observed in whales (Cassoff et al., 2011). Immediate death can also be caused because of reduced ability to escape from predators, or ship strike (Beck and Barros, 1991; Butterworth et al., 2012). Litter induced reduced mobility and agility can also lead to death by starvation.

Hence, numerous individuals die as a consequence of entanglement in marine litter. It is however likely, that a much larger number of individuals are compromised by sublethal effects that have not been fully reported (CBD 2012; Gall and Thompson 2015; Kühn et al., 2015). Chronic (sublethal) effects alter the biological and ecological performance of an individual over time in a potentially accumulating amount. A number of negative sublethal effects have been reported, including reduced mobility, agility, ability to ingest food and ability to digest food. All of which lead to reduced fitness, reproductive success and mobility.

Tissue damage is a widespread result of entanglement. Skin lesions with ulceration can result (CMS, 2014). Death of muscle tissue (necrotising myositis) is also known (Oros et al., 2005). Rope and line ligatures can cause amputation or wounds that leave sites open to infection, further reducing the likelihood of survival. For example in turtles, entanglement is known to result in the loss of flippers. The loss of one flipper appears not to reduce the geographical range of the affected animal, whereas the loss of two flippers severely limits diving and feeding ability. In addition, flipper stumps are vulnerable to further attacks by predators such as sharks, birds or crabs, which can have implications for the probability of secondary infection or predation (Carrington, 2013).

As the animal grows, rope loops cut into the skin, muscle and sometimes even bone. The loss of fins and tails of whales, dolphins, porpoises or sharks per se is unlikely, but damage and deformation to the tail have been observed. If it affects the bilateral axis of symmetry along the spine (midline), it is considered a very serious injury (Andersen et al., 2008). The constriction can become tight enough to sever arteries and finally cause strangulation. In whales, massive proliferations of new bone growth have been observed, in an attempt to wall off constricting, encircling lines (Cassoff et al., 2011). Plastic is so durable in the marine environment that when an entangled animal dies, the debris may return to the sea with the potential to entangle another animal.

2.2.3 Types of litter of concern

The majority of reported encounters by individual marine organisms were with plastic litter. The frequency of impacts varies according to the material the litter is made of, as well as the type and shape of litter items. Over 80% of recorded encounters were associated with plastic litter while paper, glass and metal accounted for less than 2% (CBD 2012). Certain categories of litter are, due to their shape, much more prone to cause entanglement. Loops or tangled string shaped items, such as packaging bands, netlike structures, ropes, cable ties or plastic bags present an elevated risk of entanglement.

By an extensive literature review taking into account scientific journals, government papers, reports by NGOs, websites of beach clean-up organization and presentations given by researchers Butterworth et al. (2012) identified litter items that are most frequently associated with entanglement: net fragments, rope and line (e.g. gill and trawl nets, lost or discarded line for pots and traps), monofilament line, packaging bands, plastic circular rings and packaging such as multipack can rings. By looking at available data, first entanglement hotspots were also suggested, e.g. the North Sea for grey seals, minke whales and gannets.

The results of a study commissioned by the United States National Marine Debris Monitoring Program indicated that 32.3 % of beach litter obtained from dedicated clean-ups across the United States had the potential to entangle animals. From the nine items which contributed to this total, the five most numerous were plastics bags of less than one meter length, balloons, rope longer than one meter, fishing line and nets (Sheavly, 2007). In the United Kingdom, fishing related litter including line, nets, buoys and floats is the second biggest source of marine litter (MSC, 2007).

A closer look at the TG ML litter category list reveals that 44 of the 217 litter categories pose an elevated risk for entanglement (see Annex I). Most of these are fishing related items, such as nets, traps and ropes. Occasionally also other items may cause entanglement incidents. In general derelict or discarded fishing gear ranks as an especially problematic marine litter type for entanglement. The estimated 640.000 tons of fishing gear lost, abandoned or discarded annually world-wide may continue to fish for years or even decades, a process referred to as 'ghost' fishing (Cheshire et al., 2009). Of the litter items recorded on the coasts during beach litter surveys in the North-East-Atlantic from 2009-2014 around a third are related to fishing activities (OSPAR, Intermediate Assessment 2017, in publication). Around 25 000 nets may be lost or deliberately discarded in European fisheries each year with a total length of 1 250 km (Brown et al, 2005). WWF estimated for the Baltic Sea and for 2011 alone that 5 000 – 10 000 gill nets were lost. According to scientific research the remaining fishing capacity of ghost nets varies from 6-20% of their initial fishing capacity. Gillnets, and traps and pots are perceived as the two types of fishing gear with the greatest risk of ghost fishing (Poseidon Aquatic Resource, 2016).

There are both direct and indirect damaging impacts of abandoned, lost or discarded fishing gear (ALDFG) in marine ecosystems. Derelict gear can be the greatest anthropogenic threat to endangered species such as the Hawaiian monk seal and causes significant mortality for other marine mammals, seabirds and invertebrates (Gilardi et al., 2010). The condition of the gear at the point of loss is important, it may operate at maximum fishing efficiency and be slow to collapse, or is already in a snagged state making it more prone to collapse immediately becoming dangerous for benthic flora and fauna (coral, sponge, seagrass, etc.) by causing physical damage and smothering.

A thorough and extensive examination of the impacts of ALDFG on marine biodiversity is likely to markedly increase the number of species identified as impacted by marine debris, as detailed reports of species entangled in ALDFG are not readily available for some regions. Analysis of data collected by long-term derelict gear retrieval programmes (Puget Sound, U.S.A.) have estimated that the almost 5000 nets removed from this one location were entangling more than 3.5 million animals per year including 1300 marine mammals, 25 000 birds, 100 000 fish and over 3 million invertebrates. An estimated 76 birds, 153 fish and 1100 invertebrates were killed per year through entanglement in a single gill net, including losses through decomposition and consumption. The impacts of ghost fishing on marine communities have not been clearly determined yet, but the high mortality rates reported for Puget Sound, particularly for invertebrates, suggest that ghost fishing effects could be significant (CBD, 2016).

Sancho et al. (2003) considered lost tangle nets to catch an equivalent of around 5% of the total commercial catch in northern Spain, while in a cage trap fishery in Canada, the ghost fishing mortality was estimated to be equivalent to 7% of landing in the sector (Breen, 1987). Pecci et al. (1978) found that in a fishing area of USA that ghost-fishing mortality caused by lobster trap on *Homarus americanus*, accounted for an equivalent of 13% of the fishing effort. The decline of deep water sharks in the North Atlantic has been linked to ghost fishing in the North Atlantic, indicating the potential for a population level impact (Large et al., 2009).

2.2.4 Case studies: Entanglement

Examples of species differences in potential harm from entanglement

Temporal data on entanglement trends is difficult to establish as it differs between species groups and population changes play an important role (Ryan et al., 2009). Nevertheless, for some species data for different populations are available, allowing a first comparison and evaluation of the potential influence of marine litter on these species.

Northern gannets *(Morus bassanus)*

Some birds use marine litter for nest building. As the artificial material used by them mainly consists of remains of fishing nets, lines and ropes, gannets as well as other breeding seabirds are highly vulnerable to entanglement in their breeding colonies including the North East Atlantic region. The Northern gannet is the largest seabird in the North Atlantic with a wingspan of up to 180 cm and a weight between 3 and 3.5 kg. They are top predators in the marine ecosystem and spend most of their lives at sea. Gannets are on land only for breeding and prefer rocky cliffs as breeding sites. These sites often comprise huge colonies which sometimes constitute more than 40 000 breeding pairs. Some of these colonies are intermixed with other seabird species.

Figure 1: Northern Gannets (source: Peter Hübner)

A study by Votier et al. (2010) investigated the use of plastics as nesting material in addition to natural materials like seaweed and sea grass by northern gannets for the years 1996-1997 and 2005-2010 in the third largest gannet colony in the world (Grassholm, Wales), where approximately 40.000 pairs of gannets breed. On average gannet nests contained 470 g (range 0-1293 g) of plastic, equating to an estimated colony total of 18.46 tons (range 4.47- 42.34 tons). The majority of the items used as nesting material was rope made from synthetic fibres (83%), followed by synthetic netting (15%), plastic packaging (2%) and a very small proportion of other plastics (<1%). The associated levels of mortality were assessed as well. On average 62.85 ± 26.84 (range minima 33-109) birds were entangled each year, in total 525 individuals over eight years, the majority of which were nestlings. A study by Bond et al. (2012) assessed the prevalence and composition of fishing gear debris in the nests of northern gannets and found a correlation with fishing effort in adjacent waters. Deformation of bills have been observed in entangled gannets likely to impair feeding (Rodriguez et al., 2013).

In a pilot monitoring effort applying the protocol as advised by the MSFD GES TG ML (2013) recordings of entangled birds and litter in nests were carried out in Helgoland, Germany during 2014 and 2015. In the pre-breeding season in March/April the entanglement victims from the previous year were assessed, during the breeding peak in June and July entanglement and litter in the nests was recorded and in the past-breeding season in September/October only entanglements were recorded. In 2014 of the 265 nests (40% of the entire gannet colony) documented 97% contained plastic litter, in 2015 of the 345 nests (50% of the entire gannet colony) 99% contained plastic litter. The plastic litter was dominated by nets and pieces of nets, cords, strings and ropes as well as relevant amounts of packaging.

In the 2015 breeding season, 33 Guillemots (which breed together with the Gannets), 12 adult Gannets and 14 immature Gannets were found fatally entangled. Two immature Gannets located close to the cliff top walkway could be caught and set free again. As they only survived because of human intervention they can still be regarded as entanglement victims. The annual natural mortality rate of 0.5% of adult gannets has increased due to entanglement to 4-8% annually, meaning that losses due to entanglement are 2 to 5 times as high (Dürselen et al., in publication). In addition, the torturous death, which lasts sometimes for weeks, constitutes an ethical and severe animal welfare problem.

Grey seals *(Halichoerus grypus)*

Available estimates of the average entanglement rate for pinnipeds are around 1% of the population, with a range from 0.001% to 7.9% for a particular population of Californian Sea Lions. These estimates have been made for 13 species of which six are migratory, including the harbour and grey seal. Mortality rates caused by entanglement range world-wide from 16% to 80 % (Butterworth et al., 2012).

Figure 2: Grey seal (source: Salko de Wolf, EcoMare)

Observations and a photo identification catalogue from a haul out site in southwest England were used to record entanglement of grey seals. Between 2004 and 2008 the annual mean entanglement rates varied from 3.6 % to 5% indicating a clear population level impact. 64% of the 58 recorded entanglements had caused physical injuries, either causing a constriction or a wound, or both. Of the 15 cases where the debris causing the entanglement was visible, 14 were entangled in fisheries materials (Allen et al., 2012).

A study on the Dutch coast between 1985 and 2010 observed that entanglement was more prevalent in grey seals than in harbour seals (39 versus 15 respectively), with juveniles most frequently recorded. Entanglement took place in pieces of ghost trawl nets and gill nets. Furthermore, the authors claimed that mortality due to entanglement was likely to be much higher due to the probable high rate of recovery of stranded animals in comparison to those that die at sea (Hazekamp et al., 2010). Especially weakened animals suffering sublethal effects tend to sink to the seabed rather than being washed ashore.

Entanglement in lost trawl nets or parts thereof increase the drag on an animal. A study showed, that a 400 g piece of net increased the energy requirement for a Californian Sea Lion about four times fold (Feldkamp, 1985). Entangled lactating Northern Fur Seal females spend more time at sea feeding compared to non-entangled animals and pups with entangled mothers have lower survival rates than other pups (Delong et al., 1990).

Species are different

The probability of entanglement, its severity and its outcome all depend on a number of factors. These include the physiology, feeding habits, size and behaviour of the animal involved, the locality, where the entanglement takes place, and the types of marine litter found in the animal´s environment (Butterworth et al., 2012). The actual risk of entanglement following an encounter between wildlife and a litter item will depend also on the animal´s physiology, feeding habits, size, locality and behaviour of the animal and environmental conditions, such as wave action. The way in which species become entangled depends on the animal´s body shape and behaviour, for example, especially young seals become entangled around the neck or body towards the front flippers after putting their head through plastic, rope or monofilament loops, a behaviour that is common in seals and is perhaps exploratory or playful. Cetaceans and turtles may become snagged on ghost fishing line or net around the mouth, flippers or tail that then can become entangled round the whole body.

2.3 Ingestion

2.3.1 Scale and extent of plastic ingestion by marine wildlife

A recurrent policy question is whether the ingestion of litter by wildlife has a measurable negative impact or, in other words, causes ‘harm’. Animals may ingest many types of litter including paper and processed wood etc., but synthetic materials are by far the most commonly reported. The phenomenon of plastic ingestion, whether intentional, accidental or secondary, has been documented for numerous species of wildlife.

Since the first major review by Laist (1997), the number of animal species known to ingest plastics has increased considerably, from 177 to 331 species. The recent review by Kühn et al. (2015) documents that at least 40% of the world’s seabird species (164 out of 406 species), 100% of turtle species (7 out of 7), and 50% of mammals (62 out of 123), are currently known to have ingested plastic marine debris. Considerable increases in species records for fishes (92 species) and invertebrates (6 species) are likely more related to an increased number of studies than to a sudden increase in ingestion rates. In general, evidence is growing for the ingestion of plastics by a wide range of free-living organisms, including shellfish such as mussels and oysters, lugworms, shrimps and zooplankton (e.g. Van Cauwenberghe et al., 2012, 2014; Leslie et al., 2013; Devriese et al., 2015). The Kühn et al. (2015) review only deals with records of ingestion in animals from the wild, and does not include experimental ingestion records.

The proportion of species ingesting plastics differs per group. Among seabirds, the most prominent group ingesting plastics is the tubenoses (Procellariiformes: albatrosses, shearwaters, petrels, storm- and diving-petrels): records on ingested plastic were known for 60% (84 out of 141) of the species. Next are the Charadriiformes, which include waders, skuas, gulls, terns and auks, with a reported 40% (55 of 139) of species known to have ingested plastics. Detectability of plastic ingestion in part depends on the type of digestive system in a species or group. For example, most tubenosed seabirds tend to retain debris in a muscular stomach for grinding and ultimate passage through the intestines. However, most Charadriiformes bird species tend to regularly regurgitate bolls of poorly digestible components from their diet.

Our knowledge on scale and extent of plastic ingestion by marine biota decreases somewhat with the size of animals and inherently with the size of the plastic particles. In the wild, occurrence of plastic has been shown in benthic worms (Van Cauwenberghe et al., 2012), shrimps (Devriese et al., 2015) and shellfish (De Witte et al., 2014). Elsewhere plastics have been recorded in similar species, but also in small zooplankton (Desforges et al., 2015) and goose-barnacles (Goldstein and Goodwin, 2013).

Table 3: Number of species with records of ingestion of litter documented in relation to the number of species known (source: adapted from Kühn et al., 2015)

Species Group	Number of known species	Number of species with recorded ingestion	Comments
Marine mammals	123	62 (50.4%)	baleen whales 54%; toothed whales 62%, true seals 21%, eared seals 62%
Seabirds	406	164 (40.4%)	Tubenoses 60%
Marine turtles	7	7 (100%)	
Fish	32554	92	Too little sampling for %
Invertebrates	c. 159 000	6	Too little sampling for %

In a recent review of plastic ingestion by marine turtles, Schuyler et al. (2013) were able to specify that the incidence of debris in turtles varies by species between 15% to almost 50% of investigated individuals. Smaller, oceanic-stage turtles were more likely to ingest debris than coastal foragers, whereas carnivorous species were less likely to ingest debris than herbivores or gelatinovores. Leatherback turtles feed exclusively on jellyfish and other gelatinous organisms, so it is at the greatest risk of both lethal and sublethal effects from ingested marine debris such as plastic bags.

There is a growing body of publications on ingestion by fish and invertebrates (Kühn et al., 2015). For example, Boerger et al. (2010), Davison and Asch (2011) and Van Noord (2012) showed that lantern fish (*Myctophidae*) in the Pacific commonly ingest plastics. Davison and Asch firmly showed that 9.2% of Myctophids in the North Pacific gyre area had plastic in the stomach. In the European region, among 10 fish species from the Channel area, Lusher et al. (2013) recorded 36.5% individuals as containing plastic, with the inclusion of very small fibres. In the North Sea among seven common species, Foekema et al. (2013) found overall a lower 2.6% of individuals with plastic fragments in the stomach but did not include fibres in their study. They found increased numbers of fragments towards the polluted Channel area, with up to 33.5% of cod affected. Romeo et al. (2015) recently reported that about 18% of large pelagic fishes in the Mediterranean (tuna, albacore, swordfish) had plastic litter in their stomachs. In a pilot study stomachs and intestinal tracts of 258 pelagic and 132 demersal fishes derived from North and Baltic Sea were analyzed for the presence of microplastics. 69 % of the fish samples were microplastics positive, nine polymer types (PE, PP, PS, PET, PVC, PA, PC, PUR, PMMA) were detected, representing more than 80% plastic types produced (Scholz-Böttcher et al., in publication).

Along the west coast of the UK, Murray and Cowie (2011) found that 83% of Norwegian Lobsters (*Nephrops norvegicus*) contained plastics. The occurrence of plastic particles was detected in 77% of 64 Japanese anchovy (*Engraulis japonicus*) sampled in Tokyo Bay, with 2.3 pieces on average and up to 15 pieces per individual and all of the particles were identified by Fourier transform infrared spectroscopy, with most of them being polyethylene (52.0%) or polypropylene (43.3%) (Tanaka and Takada, 2016). A review on microplastic quantification in aquatic animals reports an average load of 0.13 ± 0.14 total microplastic particles g^{-1} w.w. in mussel meat (Vandermeersch 2016).

In many cases, larger vertebrate species like marine birds, mammals and fishes will ingest plastic debris more or less intentionally, taking it from the ocean surface, the water column or seabed because of it resembling prey in shape and/or colour. Plastic litter might also be taken up when mixed in attractive food-wastes discarded from ship galleys. However, many records have an unclear background. For example, although it might be expected that indiscriminate filter feeders are most likely to ingest litter, this is not always the case: Kühn et al. (2015) found 54% of baleen whale species had ingested plastic debris, but among toothed whales, most of which forage by specialized hunting of known targeted prey, a higher percentage of 62% of species is known to have ingested debris. Baulch and Perry (2014) recently calculated that up to 31% of individuals are affected in some whale species. In smaller species, filter feeding and indiscriminate bottom detritus feeding are common modes of foraging that are likely to enhance the risk of non-intentional plastic ingestion.

When mammals strand, they present a unique opportunity to obtain insights into their ecology including quantification of litter content in stomachs. Large amounts of marine litter were found in stranded sperm whales. In one case in the Mediterranean Sea the items found could be linked to the omnipresent greenhouse industry along the coasts of Almeria (Stephanis et al., 2013). A remarkable number of 30 sperm whales beached along the coasts of the North Sea between January and February 2016. The gastro-intestinal tracts of 22 of the carcasses were investigated. Marine debris including netting, ropes, foils, packaging material and a part of a car were found in nine of the 22 individuals. While none of the items was responsible for the death of the animal, the findings demonstrate the high level of exposure to marine debris and associated risks for large predators, such as the sperm whale (Unger et al, 2016). In May 2013, three True´s beaked whales (two adult females and a female calf) stranded on the north and west coasts of Ireland and the contents of their stomachs was investigated. Polyethylene macroplastic fragments were found in the adult animals as well as microplastics which were identified in all stomach compartments and in 17 of 20 sections of the intestine. Ingestion or incorporation of micro- and nanoplastics by the smallest organisms including algae and consequential harm through food chains by stepwise ingestion by higher food web levels is an issue of increasing concern (Lusher et al., 2015) affecting organisms through physical (chapter 2.3) as well as chemical pathways (chapter 2.4) and viewed in the light of ultimate potential risks to humans (Galloway, 2015).

Ingestion of plastic has been reported from all around the world, e.g. Van Franeker and Bell (1988) showed that 75% of Wilsons Storm Petrels chicks (*Oceanites oceanicus*) in Wilkes Land, continental Antarctica had plastics in their stomachs, before ever leaving the ‘pristine’ Antarctic continent. Also Ainley et al. (1990) reported ingested plastics in Antarctic seabirds, albeit in lower levels than seen in more Northern waters. Eriksson & Burton (2003) reported microplastics in the faeces of Fur Seals from sub-Antarctic Macquarie Island, probably ingested through their diet containing myctopid fishes.

Table 4: Frequency of plastic ingestion for selected species populations

Species	Size of sample	% individuals with ingestion	Geography	Sources

Species	Size of sample	% individuals with ingestion	Geography	Sources
Norway lobster ***Nephrops norvegicus***	120	83%	Clyde Estuary, Scotland	Murray & Cowie 2011
Atlantic herring ***Clupea harengus***	566	2%	North Sea	Foekema et al., 2013
Whiting ***Merlangius merlangus***	105	6%	North Sea	Foekema et al., 2013
Horse mackerel ***Trachurus trachurus***	100	1%	North Sea	Foekema et al., 2013
Haddock ***Melanogrammus aeglefinus***	97	6%	North Sea	Foekema et al., 2013
Atlantic cod ***Gadus morhua***	80	13%	North Sea	Foekema et al., 2013
Northern fulmar ***Fulmarus glacialis***	1295	95%	North Atlantic	Van Franeker et al., 2011
Common Murre ***Uria aalge***	220	2.3%	Wales, UK	Weir et al., 1997
Razorbill ***Alca torda***	81	1%	Wales, UK	Weir et al., 1997
Red-throated Loon ***Gavia stellate***	19	5%	Wales, UK	Weir et al., 1997
Black-headed Gull ***Larus ridibundus***	18	11%	Germany	Schwemmer et al., 2012
Cory's Shearwater ***Calonectris borealis***	49	96%	Mediterranean Sea	Codina-Garcia et al., 2013
Harbour seal ***Phoca vitulina***	107	11.2%	North Sea	Bravo Rebolledo et al., 2013
Harbour porpoise ***Phocoena phocoena***	42	11.9%	Black Sea	Tonay et al., 2007
True's Beaked Whale ***Mesoplodon mirus***	3	66.6%	Ireland	Lusher et al., 2015
Sperm Whale ***Physetermacrocephalus***	22	40.9 %	North Sea	Unger et al., 2016
Loggerhead Turtle ***Caretta caretta***	121	14%	Mediterranean Sea, Sardinia	Camedda et al., 2014
	31	71%	Mediterranean Sea, Italy	Campani et al., 2013
	54	79.6%	Mediterranean Sea, Spain	Tomás et al., 2002
	2214	40.4%	Mediterranean NW	Darmon et al., 2014
Marine turtles (all species)	153	35.4%	NE Atlantic	Darmon et al., 2014

A comprehensive recent review provided by Kühn et al. (2015) indicates that at least 331 species are confirmed to ingest marine litter. However, this is likely to represent a substantial underestimate as a consequence of small sample sizes. Ingestion is widespread, because some species unavoidably consume plastic indirectly through their prey when plastic particles are incorporated in the fish or zooplankton that they consume. A well-known example of such secondary ingestion are skua's predating on other seabirds (scavenging or predatory seabirds like skuas and gulls will ingest plastic indirectly when eating the internal organs of for example a petrel). Other species, not yet documented to have ingested plastics, may nevertheless be regular consumers, but may regurgitate indigestible prey remains on a daily basis (e.g. cormorants and most *Charadriiformes*).

2.3.2 Types of litter of concern

The link the ingestion of plastic by marine organisms to specific litter items is much harder to obtain than for cases of entanglement. Non-identifiable plastic fragments resulting from the degradation of bigger items dominate the findings in many regions. Of the litter items recorded on the coasts during beach litter surveys in the North-East-Atlantic from 2009-2014 non-identifiable plastic and polystyrene fragments together with fisheries related items dominated the findings (OSPAR, Intermediate Assessment 2017; in publication). Similar results were obtained from 180 beach litter surveys in the coastline of the Adriatic and Ionian Seas (Vlachogianni et al., 2016).

Small plastic fragments of sufficiently small size to be taken into the mouth of birds and turtles are of special concern, capable of either obstructing the gut or replacing space, causing starvation (Butterworth et al., 2012). Different species are ingesting different sorts of litter. E.g. sea turtles may mistake plastic bags for jellyfish, plastic waste (including net fragments) taken in baleen whales during filter feeding while birds may confuse scraps of plastic bag for fish or other prey (Butterworth et al., 2012). Fish are also known to ingest plastic pellets (Derraik, 2002; Gregory, 2009) as it is also well known for fulmars and other petrels (see below).

2.3.3 The impact of plastic ingestion on the fitness of individuals

The above figures in Table 4 make it clear that wildlife frequently encounters plastic debris and that ingestion is a regular and widespread phenomenon among all groups of marine organisms. Individuals suffering and death as a consequence is unavoidable, and has been indisputably documented for all groups of air-breathing marine life, mammals, birds and turtles alike. However, these issues become harder to document at lower tropic levels and small-sized organisms. Most importantly, sublethal effects that do not directly lead to the death of the individual but are of importance to populations, are extremely difficult to quantify.

2.3.3.1 Direct mortality of individuals as a consequence of ingestion

Ingested plastic may lead to rapid death when stomachs or intestines become completely blocked or severely damaged. Even small particles of debris may cause the blockage of the intestines of animals (Bjorndal et al., 1994). An ingested straw led to the death of a Magellanic penguin (*Spheniscus magellanicus*) by perforation of the stomach wall (Brandao et al., 2011). Examples of lethal impacts in seabirds are described in Kenyon and Kridler (1969), Pettit et al. (1981) and Colabuono et al. (2009). Direct mortality in marine turtles has been described by e.g. Bjorndal et al. (1994), Bugoni et al. (2001), Mrosovsky et al. (2009) and Tourinho et al. (2010). Unlike most birds, turtles often seem to pass plastic debris easily into the gut, and therefore most plastics have been found in the intestines rather than the stomach (e.g. Bjorndal et al., 1994; Bugoni et al., 2001; Tourinho et al., 2010, Campani et al., 2013). Consequently, individual death or harm in turtles may often be related to gut functioning. In the Mediterranean Sea, the death of a sperm whale of 4.5 t, was attributed to 7.6 kg of plastic debris in its stomach, which was ruptured probably due to the large plastic load (De Stephanis et al., 2013). Often, it is difficult to produce firm evidence for causal links between ingested debris and mortality. Therefore, solid proof that ingested debris was the direct and sole cause of death is rare (Sievert and Sileo 1993; Colabuono et al., 2009). Documentation for direct mortality in lower food web levels and smaller organisms in their natural lives is extremely difficult. In marine fishes individual cases for direct death and/or suffering from plastic ingestion clearly do occur but are rarely documented (e.g. Anonymous 1975). As far as is known, there are no documented cases in the natural environment of direct death from ingestion in invertebrates such as crustaceans, zooplankton, benthic worms etc. At all trophic levels, direct mortality from plastic ingestion probably does not occur at a frequency relevant to the population level. Indirect, sublethal effects are likely to be much more relevant.

2.3.3.2. Sublethal physical impacts from ingestion

In the larger marine vertebrates, ingested plastics are known to cause direct physical damage to the various components of the intestinal tract, i.e. oesophagus, stomach(s), and gut (e.g. Beck & Barros 1991; Baird & Hooker 2000; Mauger et al., 2002; Pierce et al., 2004; Jacobsen et al., 2010; Poppi et al., 2012; Stahelin et al., 2012). The damage may vary from perforations, inflammations and ulcerations, that are not necessarily lethal but do affect the functionality of the digestive system and health of the individual. Accumulated plastic in stomachs may slow down overall digestion when normal food simply cannot pass to specific parts of the stomach or the gut. Reduced functionality may also occur because plastics 'seal off' parts of walls that have a function for production of digestive enzymes in the stomach or uptake of food in the gut.

Anywhere in the digestive tract, plastics may cause partial blockage or constipation reducing the amount of food that can pass, and causing weakening and emaciation of the individual. Examples of such mechanical sublethal impacts, including recovery after removal of the plastic blockage, are known from mammal and turtle rehabilitations (Stamper et al., 2006; Stamper et al., 2009).

In the digestive tract, even without blockage, volume occupied by plastic waste reduces the space available for maximum food intake. Seabirds generally have large stomachs to be able to utilize short periods of abundant food supply and then go without food for a long time. But not all species have this ability. A reduction in available stomach volume will certainly reduce the chances of survival, especially in extreme weather conditions such as high winds or low temperatures.

A more serious issue is that a stomach filled with plastic can cause a false sense of satiation reducing the stimulus for the individual to eat, even when such would be necessary. Experimental evidence for this type of effect was most clearly obtained by Ryan (1988) showing that chickens with plastics in their stomachs ate less and grew more slowly than control birds because they took smaller meals even when sufficient food was available. Experiments with wild albatross chicks indicated similar negative effects for fledging seabirds (Sievert and Sileo, 1993)

An investigation of 106 Franciscana dolphins in Argentinian coastal waters found 28 % of the dolphins containing plastic in their stomach, but no ulcerations or obstructions were recorded in the digestive tracts. Plastic ingestion was suggested to cause sublethal effects, such as partial obstruction of the gastrointestinal tract and reduction of feeding stimulus, compromising the energy consumption and its health (Denuncio, 2011).

In recent years a considerable number of experimental studies have been conducted on potential impacts of microplastic ingestion. These experiments have predominantly been conducted on lower food web levels, including fishes (e.g. Mattsson et al., 2014; Luis et al., 2015; Cedervall et al., 2012; Peda et al., 2016), crustaceans (Setälä et al., 2014; Brennecke et al., 2015), zooplankton (Cole et al., 2013; Lee et al., 2013; Besseling et al., 2014; Cole et al., 2015), benthic worms (Browne et al., 2013; Wright et al., 2013), shellfish (Browne et al., 2008; Avio et al., 2015; Sussarellu et al., 2016), sea-urchins (Nobre et al., 2015) and even corals (Hall et al., 2015). See also recent reviews by Lusher (2015) and GESAMP (2015). Under the experimental conditions, negative impacts on individual body condition, reproductive capacity and survival have been demonstrated. While some studies have exposures at concentrations higher than those currently reported in the environment others have used levels of contamination that resemble conditions in heavily contaminated marine sediments (e.g. Wright et al., 2013). Hence, it seems likely that microplastic particles can exert sublethal effects on natural populations. Impacts may operate by physico-mechanical effects, chemical toxicity (Chapter 2.4) or combined effects. (see reviews such as Lusher (2015), GESAMP (2015)).

In wild birds, reduced body condition through lower fat reserves or proteins, may go unnoticed for much of their life cycle, but will result in reduced individual fitness for survival during e.g. winter food shortages or fitness for successful reproduction. Such sublethal effects are hard to quantify in direct linkage to a particular cause, as many factors together will in combination determine the fitness of the individual. The same applies to potential sublethal impacts from chemicals or degradation substances associated with the ingestion of plastics.

2.3.4 Case studies: Ingestion

Examples of species differences in potential harm from ingestion

Combined impacts on fitness for a species will be linked to the proportion of animals ingesting plastics, in combination with the amounts and types of plastics ingested, and the anatomy and type of digestive system of the birds. Such level of detailed knowledge is currently restricted to a few example species.

Laysan Albatross - *Phoebastria immutabilis*

The best-known example of plastic ingestion is that of the Laysan Albatross especially in the northern extent of the Hawaiian Islands. Chicks of this species accumulate large quantities of plastic in their stomach, brought to them by their parents. There are virtually no chicks without plastic in their stomachs. In many cases the whole proventriculus is filled up with a strongly compacted ball of plastics and squid beaks, which is often regurgitated before fledging, but sometimes becomes stuck within the stomach.

Figure 3: Layson albatross (source: Jan van Franeker)

This plastic ball certainly reduces the potential for 'real' food intake during the growth period. It seems clear that not all plastics are regurgitated; part of the ingested material does pass into the intestines. Sileo et al. (1990) reported that 39% of guts investigated contained identifiable remnants of plastic. Auman et al. (1997) provided clear evidence that chicks that died before fledging had substantially more plastics in the stomach and substantially lower body mass than the average chick during the same period (derived from lower quantities of plastics found in stomachs of chicks that died in road kills). Ingested plastics thus contribute to higher than natural mortality rates among chicks, and thus have an impact at the population level. The adults themselves seem to have lower amounts of plastics in their stomachs (Gray et al., 2012). Population trends in this species seem variable, but the species has not recovered from earlier high hunting pressure and is therefore listed as 'Near Threatened' in the IUCN (2012) Red List. Reduced fledging success and delayed effects of plastic ingestion on all chicks in the population must be considered as a 'population impact' that is playing a role in this lack of recovery, combined with other factors affecting the populations. No data seem to exist on plastic ingestion by the much rarer Short-tailed Albatross (*Phoebastria albatrus*) which has an estimated population of fewer than 2500 individuals in the North Pacific. This species was hunted to near extinction and is very slowly recovering, but is still rated as 'Vulnerable' by IUCN (2012). However, for this species similar impacts from plastic ingestion must be assumed and are of high concern in such a small population.

Northern Fulmar – *Fulmarus glacialis*

Fulmars from in and around the North Sea virtually all ingest plastics on a regular basis. At any point in time, roughly 95% of all individuals have plastics in the stomach. It is estimated that plastics are 'processed' in the stomach and passed on to the gut fairly quickly, decreasing in the stomach by about 75% per month on mass basis (Van Franeker et al., 2011; Van Franeker & Law 2015). So,

Figure 4: Northern Fulmar (source: Jan van Franeker)

physical sublethal effects from the accumulation of litter in gizzards, and chemical sublethal effects from a constant grinding of plastic litter, are certain to occur in almost every adult bird of the population. During a mass mortality of Fulmars in the North Sea in 2004, several indicators suggested a background of hormonal disturbance, which could well be related to persistent high levels of chemicals, some of which may have derived from plastics, circulating in their bodies during a period of prolonged food shortage (Van Franeker et al., 2011). After a long period of population growth, the trend seems to have stopped or reversed since late 1990s and reproductive success is at present frequently poor. Many factors are involved in these developments, but reduced adult survival and reduced reproductive output as a consequence of plastic ingestion are population effects that will play a role contributing to the population trends.

Loggerhead Turtle – *Caretta caretta*

Figure 5: Loggerhead Turtle (source: Marijke de Boer)

It appears that passage of debris through the digestive system of turtles is very different to that of any of the seabird species. Passage through the stomach seems rapid, with most litter found not in the stomachs but in the intestines. Camedda et al. (2014) report that in studies of dead specimens, 70% of the litter was found in the intestines, and only 30% in the stomach. This probably means that the 'flux' of plastics through turtles is likely to be substantial, although the possibility for long residence in the intestine cannot be excluded as in rehabilitation centres defecation of plastic debris has been observed two weeks to a month after arrival in the centre (Mascarenhas et al., 2004; Stamper et al., 2009). If particles of debris become stuck in intestinal areas, the type of damage may be different from that observed in seabirds. Balloon fragments were experimentally shown to have a tendency to conglomerate to balls in the intestines of freshwater turtles (Irwin, 2012) which likely hampers the passage of food.

Species are different

The aforementioned examples emphasize that the commonly used indicator species cannot be used to detect effects on other species. This urges for a precautionary approach. The differences between the Laysan Albatross (impact from litter accumulation in stomachs of fledglings, probably most important) and Fulmar (main impact on adults through life-long continued ingestion) and turtles (main impact possibly in their intestines) are already illustrative. At a certain level of plastic debris abundance, ingestion rates for a given species may not seriously affect its population, whereas at the same time another more sensitive species, that has not been studied, could be suffering serious population impacts. For example, plastic was found in 75% of stomachs of dead Wilson's Storm Petrel chicks (*Oceanites oceanicus*) in the Antarctic (Van Franeker & Bell 1988), which might well affect their survival as adults and their reproductive output. However, populations of this species breed dispersed and hidden in inaccessible remote Antarctic areas and would have to be in a serious state of decline before an impact will be noticed at the population level. Similarly, phalaropes forage on small zooplankton from the sea surface and frequently ingest plastics and therefore should be considered as a sensitive group of birds for harm induced by plastic pollution. However, studies on stomachs of phalaropes are difficult as such small birds are rarely recovered in beached bird surveys, and population trends of these dispersed breeders in arctic tundra areas are very difficult to assess. The complicated ways in which plastic ingestion affects certain individuals and species exemplifies how difficult it is to evaluate such impacts on groups of individuals in populations, species, let alone species assemblages. And even then, ingestion of litter is only one of the many factors that interact in the final factors that ultimately define the wellbeing of populations and higher assemblages (see also chapters 2.6 and 2.7).

2.4 Transfer of chemical substances

There are two ways in which it has been suggested plastics might act as a vector facilitating the transport of chemicals to organisms upon ingestion. Some plastics contain potentially harmful chemicals that were incorporated during manufacture. These additives include plasticisers, antimicrobials and flame retardant chemicals that could be released to organisms upon ingestion (Rochman & Browne, 2013; Oehlmann et al., 2009). In addition to the release of additive chemicals plastics are known to sorb persistent organic pollutants from water and in a matter of days, concentrations on the surface of the plastic can become orders of magnitude greater than in the surrounding water (Mato et al., 2001). If these sorbed chemicals desorb upon ingestion this could provide a route for facilitating the transfer of chemicals to biota (Teuten et al., 2007). A key challenge is to establish the relative importance of plastics in the transfer of chemicals to organisms compared to other pathways such as via food uptake or directly from seawater (Bakir et al. 2016).

The risk of transfer of chemical additives from plastics directly to humans is well documented (Galloway, 2015). In the food packaging industry for example, plastics are well-known to leach a range of chemicals to food, especially fatty substances. At sufficient concentrations, some of the leachates involved are known to be toxic, mutagenic, carcinogenic or hormone-disruptive and bio-accumulating (Muncke, 2011; Lithner et al., 2009). This route of transfer to consumers is evidenced by the strict regulations for food packaging products to ensure that only limited quantities of additives leach into food consumed by humans. It must be emphasized that only some of the plastic items eaten by marine wildlife have their origin in food packaging. Biota ingest many other types of non-food related plastic debris containing a much broader range of chemical additives, some can be present in considerable concentrations, but the potential for leaching from plastic litter is likely both prior to and upon ingestion, but the relative importance of this pathway has yet to be fully evaluated. There is evidence that organism can retain plastic once ingested. For example, many seabirds retain plastics for a long time and gradually grind them down in their muscular stomachs, in addition invertebrates have been shown to retain microplastic particles (Browne et al., 2008). Hence there is the potential for leaching and transfer of chemical additives form plastic. Work by Tanaka et al. (2013) showed chemical transfer directly from plastics to birds, since they found chemicals (specific polybrominated compounds) in the tissues of shearwaters that were present also in ingested plastic but not in the natural food items of these birds.

In addition to the potential for transfer of chemical additives; plastics adsorb chemicals from seawater and if the plastic is ingested these chemicals may also become available to organisms (Teuten et al., 2009). There is uncertainty about the relative importance of plastics as a vector in the transport of chemicals from sea water to animals (e.g. Koelmans et al., 2014). According to partitioning theory some models predict low or even reversed (from organism to plastic) transfer of chemicals between the organism and seawater as a consequence of the plastic. However, the relative importance of plastics as a vector is likely to be influenced according to a range of factors and in particular the surrounding environment. For example, the rate of release is facilitated by gut surfactants (e.g. Teuten et al., 2007), the nature of the gut fluids themselves (Tanaka et al., 2015) and is greater in warm blooded compared to cold blooded organisms (Bakir et al., 2014). Some recent experimental and modelling evidence suggests platics may not present an important pathway for the transfer of sorbed chemicals but more work would needed to assess this across a wider range of organisms (Bakir et al., 2016).

Considering transfer of additive chemicals Ryan et al. (1988) showed a correlation between the amount of ingested plastic and PCBs in shearwaters. Experimental evidence for transfer of chemicals from plastics to seabirds is difficult as many chemicals also reach top predators via the normal food web. However, evidence for plastic derived transfer of chemicals is increasing, e.g. Yamashita et al. in Teuten et al. (2009), which was supported by findings in wild birds (Yamashita et al., 2011). Similar evidence for transfer of sorbed chemicals was found for fish (Rochman et al., 2013, 2014) and lugworms (Browne et al., 2013), including indications for effects on health. Tanaka et al. (2015) investigated the accumulation of PBDEs from ingested plastics in the tissues of 18 wild seabirds which contained on average 22.5 plastic particles in either their gizzard or in their proventriculus (average weight of plastic 0.31 g per bird). This quantity is the range of the amount of plastic reported in the gut of seabirds, including Northern fulmars (Avery-Gomm et al., 2012; van Franeker et al., 2011; Blight & Burger, 1997). PBDEs were detected in all birds in both the liver and abdominal adipose tissue suggesting a possible correlation between POPs in ingested plastics and internal concentration for seabirds. However, Herzke et al. (2016) did not find the bioaccumulation of POPs to be proportional to the quantity of plastic ingested, thus not supporting the hypothesis that the presence of plastics in the organism might increase the accumulation of contaminants as has been suggested in earlier studies (Teuten et al., 2007; Rochman et al., 2013). However, retention time within the organism is an important consideration: some animals have been shown to retain plastics for several weeks (e.g. Browne et al., 2008) while animals that regurgitate indigestible stomach contents on a daily basis or species quickly passing such items through the intestines, possibly being less susceptible to chemical transfer because of the lower exposure.

Based on current laboratory studies and evidence from natural populations it is possible, but not certain, that sublethal chemical effects could occur in some wild animals as a consequence of plastic ingestion. The extent to which this might occur will depend on the individual’s ingestion rate, the degree of plastic retention, the types of plastic, the chemical contaminants, the receiving environment in the gut (e.g. pH temperature, lipid content) and the alternative pathways for the contaminants for example directly from the water or the animals regular diet (Bakir et al. 2016). Hence, from the limited data available, it is not possible to draw generalised conclusions about the potential for chemicals associated with plastics to cause harmful effects in natural populations. Further research on this topic is ongoing.

2.5 Marine litter as a vector for transport of biota

Biological invasions of non-indigenous species (species that have been transported inadvertently or intentionally across ecological barriers and have established themselves in areas outside their natural range) are one of the greatest drivers of biodiversity loss, second only to habitat loss and fragmentation, posing a threat to ecosystems integrity and functions. The most significant potential effects from the settlement of non-indigenous species are the alteration of habitats, changing native species dynamics, killing of large numbers of native species and/or competing with them, together with acting as vectors of diseases. Non-indigenous invasive species are shown in many cases to utilize litter items in oceans as habitats to hide in, as substrates to adhere to or, settle on as a transport medium for movements into new territories (Gregory, 2009; Gall and Thompson, 2015; Kiessling et al., 2015). This type of dispersion is not a new phenomenon, as natural debris (dead wood, ash, etc.) are transport media that have most probably promoted colonization by sea for millions of years. Transportation through natural or anthropogenic litter is occurring passively, without control on species, materials and transportation scheme other than hydrodynamics or environmental factors. The transport of biota on litter items is potentially a new problem, because of the recent proliferation of floating particles, which are mostly plastics. As an example, the estimated 250 billion microplastic particles floating in the Mediterranean Sea (Collignon et al., 2012) are all potential carriers of non-indigenous invasive species (Maso et al., 2003). The advantage of plastic litter as a transport mechanism is its longevity at sea and its surface properties, which favour attachment and thus the possibility of transport to new areas of both, mobile and sessile species. As a consequence, species transported by rafting can alter the composition of ecosystems (Zettler et al., 2013) and alter the genetic diversity through breeding with local varieties or species.

Rafting affects all ocean areas and waters around all continents, however, surface cover on litter items, particularly by bryozoans, as well as species richness and diversity is greatest at low latitudes, tropical and subtropical, decreases through temperate mid latitudes and is least in polar latitudes (Gregory, 2009; Gil and Pfaller, 2016). The recent example of 175 species, many of them new to North American waters, attached to large size litter fragments floating for months in the North Pacific after the 2011 Tsunami in Japan, is demonstrative of this (Gewin, 2013). In another example, in the Pacific Ocean, high concentrations of microplastic plastic pellets may act as oviposition sites for insects such as *Halobates sericeus*, enhancing the abundance and dispersion of this predator species. (Goldstein et al., 2012). Nevertheless, there is limited information available about where most stranded litter originated, or about its path of drift (Brown et al., 2015).

A total of 387 taxa, including pro- and eukaryotic microorganisms, seaweeds and invertebrates, have been found rafting on floating litter in all major oceanic regions (Kiessling et al., 2015). The extent of fouling depends on latitude, type of polymers and size of items. Species representing most invertebrate groups have been found on these "rafts" made, for the most part, of plastic. Bryozoans, pedunculated crustaceans and barnacles, worms, hydroids and molluscs are easily attached to these structures and sometimes drift over long distances. One study showed that up to 60 % of litter items on some beaches in the Indian Ocean were carriers of potentially invasive species. This phenomenon has been described previously in remote areas (Barnes et al., 2010) and seems to be very common. It depends on different factors if these new species will survive and became invasive. Plastics remove many barriers to colonization because with this type of transport the material itself can become a new habitat or promote the settlement of planktonic stages before metamorphosis in habitats where natural substrates are lacking.

Unicellular organisms are also present on floating debris. Foraminifera, diatoms, dinoflagellates, including harmful species (Maso et al., 2003), coccolithophorids, radiolarians and ciliates are frequently seen as well as many species of alga (Carson et

al., 2013, Collignon et al., 2014). They are distributed "in patches" which are affected by factors such as location, temperature, salinity, plankton abundance and plastic concentration (Carson et al., 2013). In an example, among the rich fauna found on floating microplastics sampled in the north western Mediterranean Sea, substantial specimens of a monospecific foraminiferal assemblage of the benthic foraminifer *Rosalina concinna*, were found (Jorissen, 2014). This very rare foraminiferal taxa with a planktonic (Tretomphalus) stage is favoured by sexual generation producing large floating chambers before the release of gametes when surface waters are at temperatures above 18°C. *R. concinna* was found at density of about 20 individuals per 100 cm^2 on plastic litter, comparable to its density on natural substrates. Its ability to colonize floating microplastics leads to a significant extension of the available niches, which could substantially modify the dispersal efficiency of this highly opportunistic taxon and enable a benthic species to colonize the pelagic environment.
Bacteria are potentially transported on marine litter and play an important role in the formation of primary biofilms (Zettler et al., 2013; Carson et al., 2013). Different types of floating substrates, including fishing lines and plastic bottles have been shown to adsorb pathogens known to be harmful to fish, in vitro (Pham et al., 2012), a "plastisphère" ecosystem whose consequences are not controlled (Zettler et al., 2013). In a recent study, the adhesion dynamics of *Vibris crassostreae* on polystyrene microparticles were investigated. A longer bacterial attachment (6 days) was observed on irregular compared to smooth particles (<10 h). The results further suggested that *V. crassostreae* may be a secondary colonizer of polystyrene microparticles, requiring a multispecies community to form a durable adhesion phenotype. Additional temporal assessments of microbial colonization on microplastics at sea is needed to better understand microplastics colonization dynamics and species assemblages (Foulon et al., 2016).

Sinking debris may also impact the deep-sea environment where it can be exposed to deep currents, enabling potential transport over thousands of kilometres (Bergman and Klages, 2012). Litter, by providing solid substrates and new habitats, may impact the distribution of benthic species, even in remote areas (Katsanevakis et al., 2007; Mordecai et al., 2011; Bergmann and Klages, 2012; Pham et al., 2014).
In European waters, more than 50% of the plastics found in trawling grounds from the Mediterranean were colonized by biofilms of microorganisms. In some areas, up to 12% of plastics were totally covered by larger organisms, suggesting indirect effects on benthic communities (Sanchez et al., 2013). Both total abundance and the number of species show an increasing trend of seabed communities impacted by litter because the litter provides refuge or reproduction sites previously not available or not available in such profusion. A marked gradual deviation in the community structure of the impacted surface from a control area without litter and a clear successional pattern of change in the community composition of the impacted surfaces were also demonstrated (Katsavenakis et al., 2007).

To date, incrustation of pico- to microorganisms, planktonic or benthic, on marine litter has not been described in deep sea environments. However, larger organisms such as sponges, sea anemones, hydroids and scleractinian corals, polychaetes, Bryozoa, molluscs, echinoderms, tunicates and rockfishs have been found fixed on litter from ultra-deep areas (Bergman and Klages, 2012; Fabri et al., 2013; Sanchez et al., 2013), most of them being suspension feeders.

As a consequence, the dynamics of hard-substrate-associated organisms may be important in order to better understand the ecological impacts, the dynamic of species but also the connectivity between the various compartments of the marine environment.

2.6 Marine litter altering/modifying assemblages of species

Habitat heterogeneity increases biodiversity, with natural and artificial structures typically attracting higher population densities and a wide variety of marine taxa than in areas where such structures are not available (Buhl-Mortersen et al., 2010; Levin et al., 2010; Ramirez-LLodra et al., 2011). Anthropogenic structures e.g. ships, airplanes, bridges, cars etc. are often introduced into marine ecosystems to promote recreational fishing and to create sites for diving activities.

Biodiversity loss is known to be strongly driven by habitat change, over exploitation, pollution, invasive species introduction and climate change. It is likely that marine litter is an important contributor to the anthropogenic stresses acting on habitats and biodiversity (CBD, 2012).

In the open ocean, several studies have shown that the greatest abundance of debris is originating from land (Goldestein et al., 2012; Law et al., 2010; Collignon et al., 2012; Moore et al., 2001; CBD, 2012) and accumulates in oceanic gyres as a result of geostrophic circulation. These convergence zones could be colonized not only by marine organisms but also by terrestrial ones, too.

Figure 6: Sessile marine flora and fauna on a buoy (source: Marco Matiddi)

Marine litter pollution introduces additional hard surfaces into the marine environment. Especially when litter sinks to sedimentary seabed it can create an artificial habitat, which can be colonised by organisms that would not normally occur there. Depending on the size of the litter items, they can provide habitat for faunal assemblages with taxa typically found in rocky environments. Habitat change has the potential to influence the relative abundance of organisms within local assemblages.

Taylor et al. (2014) described differences in deep-sea faunal communities associated with a lost shipping container. Their conclusions show that the dominant megafauna were markedly dissimilar to the naturally occurring species, with higher densities of individual and taxa observed on the containers’ surface in comparison to deep-sea soft sedimentary habitats. Faunal assemblages on the container were typical of rocky habitats, however, they included different taxa to the organisms occurring on natural hard substrata at similar depths in the same area. Different studies reported species colonizing derelict fishing gear as habitat (Fig. 6 and 7), including both mobile and sessile species (CBD, 2012).

Figure 7: Colonized derelict fishing gear (source: Marco Matiddi)

Another harmful effect is `smothering`, where litter, in particular plastic sheeting, films or nets, covers bottom sediments or sedentary organisms such as corals and sponges. Smothering leads to reduced fitness and even death of the organisms lying under the plastic through reduced oxygen levels and reduced photosynthesis, which in turn alters habitats and communities. As an example, a significant negative relationship between the level of marine litter cover and coral cover has been recorded (Richards and Beger, 2011), the litter causing suffocation, shading and mortality of corals. Litter can also cause physical damage to corals, compromising reef structures. When marine litter snags on reefs (Fig. 8), waves acting on the debris break off the corals heads on which the litter has snagged (Fig. 9). The item is then freed and can move on, ultimately destroying benthic reef flora and fauna (Donohue et al., 2001). In an experimental study with high densities of nano-sized plastics, it has been observed that algal cells were smothered to such a degree that photosynthesis was reduced to a level which could have potentially negative effects (Bhattacharya 2010). There is some clear evidence of effects of the presence of small quantities of debris on marine assemblages. A recent study by Green et al. (2015) showed that individual plastic carrier bags can, within a matter of weeks, alter assemblage composition and delivery of ecosystem services in saltmarshes. These smothering effects of the seabed occurred with both, conventional and 'degradable' plastic carrier bags, leading to modified gas exchange between the sediment and the water column and resulted in deleterious changes in ecosystem services. A short review of cases of smothering was included in Kühn et al. (2015).

Figure 8: Ghost net on the sea bottom (source: Marco Matiddi)

Figure 9: Ghost net snags on the violescent sea-whip (Paramuricea clavata) (source: Marco Matiddi)

In Indonesia significant differences in the abundance of meiofauna and diatoms were demonstrated in sediment samples from beneath marine debris compared to areas free from debris, with higher densities of meiofauna and lower densities of diatoms in samples affected by litter (Uneputty and Evans, 1997). Furthermore, beach litter adversely affects the ability of turtle hatchlings to reach the sea (Ozdilek et al., 2006). The hatchlings apparently being eaten by crabs when they became trapped in the litter. Finally, Aloy et al. (2011) demonstrated that a gastropod's efficiency in locating and moving towards a food item significantly decreased as the level of plastic cover increased. Plastic bags were added to the area of the shore and significantly altered foraging behaviour in areas with 50% and 75% cover by litter but no effect of 25% cover was observed. This study used high densities of plastic compared to that reported in the environment hence it is not possible to conclude, that in the amounts found in the field, debris would have similar effects.

Debris facilitates recruitment and survival of novel taxa, including alien species, while reducing foraging activity and survival of indigenous ones. Depending on habitat resilience, it can promote population increase for some species and decrease of others.

2.7 Levels of biological organization affected

Many species of marine wildlife, such as whales, seals and birds are considered threatened or endangered according to the IUCN red list. Among birds, seabirds are the most threatened group worldwide (Croxall et al., 2012) as a consequence of a broad range of negative impacts for example from fisheries (competition as well as bycatch mortality in active nets or longlines), pollution, habitat loss and introduced predators. `Threatened` being defined by the severity of the population decline and the distribution of the remaining population (IUCN, 2012). Many factors, both positive and negative, natural and man-made, and in complex combinations and interactions, regulate sizes of populations in marine ecosystems. It is not easy to single out an individual factor as the main determinant of population change, unless that factor has an overwhelmingly dominant impact, rendering all others irrelevant, which is only rarely the case. An evaluation of population level impacts must be reconstructed from known individual impacts, as ultimately the individual consequences add up to cumulative impact on populations.

From a policy perspective, the strongest evidence of harm relates to measurable changes in animal and plant communities or declines of populations or species as a direct consequence of interaction with marine litter. However, evidence of changes in populations or species is almost impossible to obtain. Nevertheless, it has been shown earlier in this report, that from the numbers of individuals affected especially from ingestion of and entanglement in marine litter, an influence at the population level is likely.

A broad range of interacting natural and human factors determine the survival and reproductive success of individual animals, the combination of which ultimately determines the numerical stability of a population or species. Even in strongly declining species it will be extremely difficult to pinpoint a single factor such as plastic ingestion or entanglement in marine litter as *the* decisive cause for the decline. For example, most species of marine turtles are in decline and red-listed by the IUCN (2012) as being (critically) endangered. Turtle declines are attributed to the cumulative negative impacts from mortality in active fisheries (bycatch in nets and long-lines), entanglement in litter and ghost-nets, hunting of adults and harvesting of eggs, habitat-loss, oil-pollution etc. The frequent ingestion of plastic litter by turtles (e.g. McCauley and Bjorndal 1999; Mrosovsky et al., 2009; Witherington et al., 2012; Schuyler et al., 2013) undoubtedly contributes to such population decline, however, its level of contribution, as well as those of the other factors, cannot be isolated.

The opposite situation also occurs, in which a single factor can have a serious population impact even when serious declines in numbers have not yet been observed. During the second half of 20th century many seabird populations around the North Sea were growing in size in spite of high mortality rates due to heavy oil and chemical pollution, which lasted for several decades. At the time these seabird species were recovering rapidly from declines due to severe hunting pressure, egg collection and the negative effects of pollution related mortality. In addition, heavy overfishing of larger predatory fish improved seabird food resources through increased availability of smaller suitable prey sizes, discards and offal. In another more natural setting, the same level of oil related mortality would certainly have been unsustainable and have resulted in serious population decline. Changes in the level of the effect of chronic oil pollution can be estimated from trends in proportions of contaminated individuals among beached seabirds (Camphuysen & Heubeck 2001), however, impacts at a population level have only been assessed for specific species in cases of short term effects following very severe oil incidents of e.g. wrecked tankers (e.g. Votier et al., 2005). As an example of plastic ingestion, Figure 10 attempts to provide a simplified schematic view of some of the many different factors that determine the ultimate wellbeing and sizes of wild animal populations. Each factor is involved in survival and reproductive success in multiple ways. For plastic ingestion, a flow chart of its, *potential*, effect is provided.

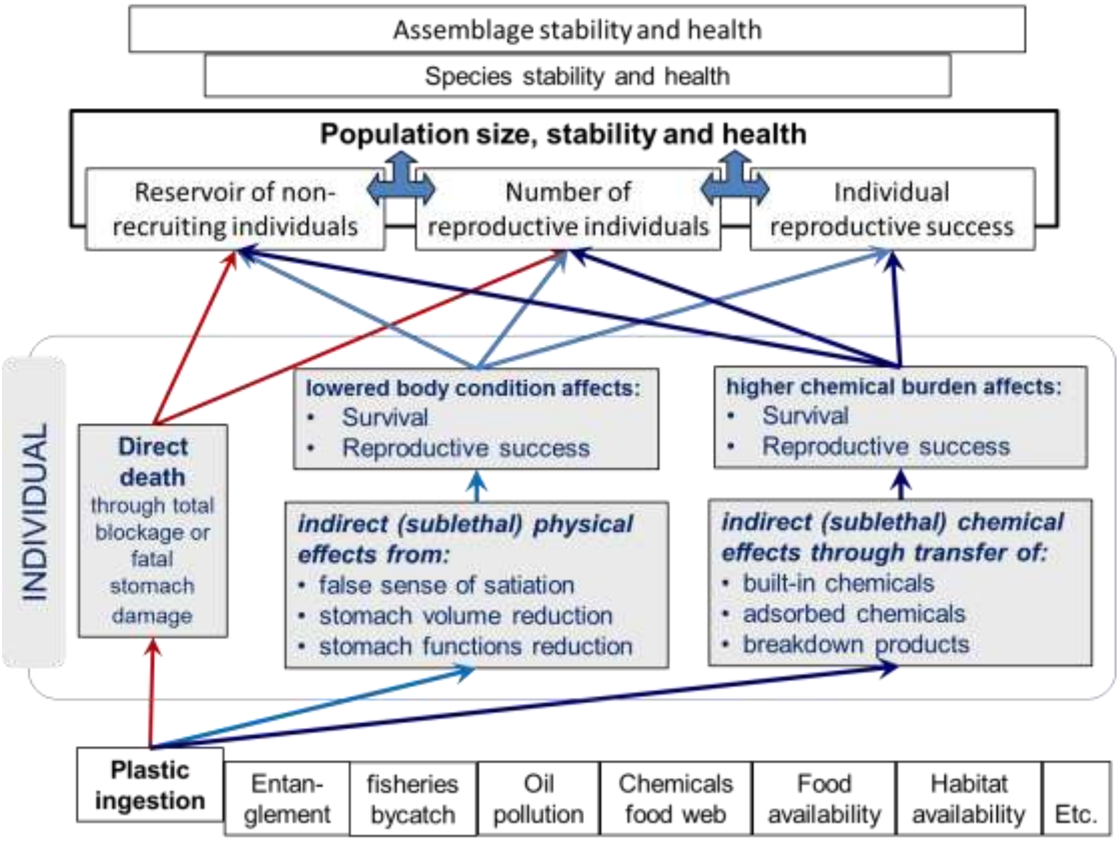

Figure 10: Schematic representation of impacts of ingestion of plastic debris through individuals to populations and higher level units. The bottom-line shows a selection of the many other interacting variables that also influence individual survival and reproductive success, complicating scientific quantitative evaluation of impacts of individual factors on populations, species or assemblages (Source: Jan van Franeker).

Reduced individual fitness, in terms of body condition and chemical body burden is known to affect seabird demographics. Lowered energy reserves reduce annual survival rates as well as breeding success; both these parameters contribute to population health and size (e.g. McCauley and Bjorndal 1999; Heubeck 2006, Chastel et al., 1995, Hegemann et al., 2013; Maness & Anderson 2013; Christiansen et al., 2013). Chemicals related to plastics can be neurotoxic, carcinogenic, hormone-disturbing etc. (e.g. Halden 2010), which when affecting a large number of animals in the population will likely translate into population effects.

The concept of ‘harm’ to wildlife is a very complicated concept. Various dedicated publications (Rochman et al., 2016; Brown et al., 2015) suggest different approaches to describe harm. In this report, any negative impact from marine litter is considered as a form of harm, including individual suffering or death of animals. Others might only consider harm to have occurred if significant numbers of individuals have suffered or died, or if populations are in serious decline due specifically to the effects of marine litter. In principle the idea that an indicator species such as those used in the MSFD should be in decline before harm can be considered to have occurred is flawed in terms of environmental quality. Indicator species are chosen because of their abundance and wide distribution which usually also means that they are robust species. Other more vulnerable species may become threatened by marine litter or even become extinct as can healthy populations too if the level of pressure caused by litter is high enough.

For example, in Europe, the population of Fulmars is estimated to have declined by more than 40% since the mid1980s, and has been red-listed by BirdLife International as 'Endangered' based on standard IUCN Criteria. Within the EU, the population status is considered to be 'Threatened'. In most of the more remote areas, population trends are poorly known (Birdlife, 2015). Conservation actions proposed in the BirdLife population assessment are: identification and protection of important sites at sea, as well as for prey species and continued monitoring of marine litter ingestion, and increased efforts for removal of plastic from oceans (Birdlife, 2015). Although hard evidence for cause(s) of decline is (are) impossible to obtain, the ingestion of plastic debris is at least considered a potential contributing threat to the Fulmar population, which needs to be addressed.

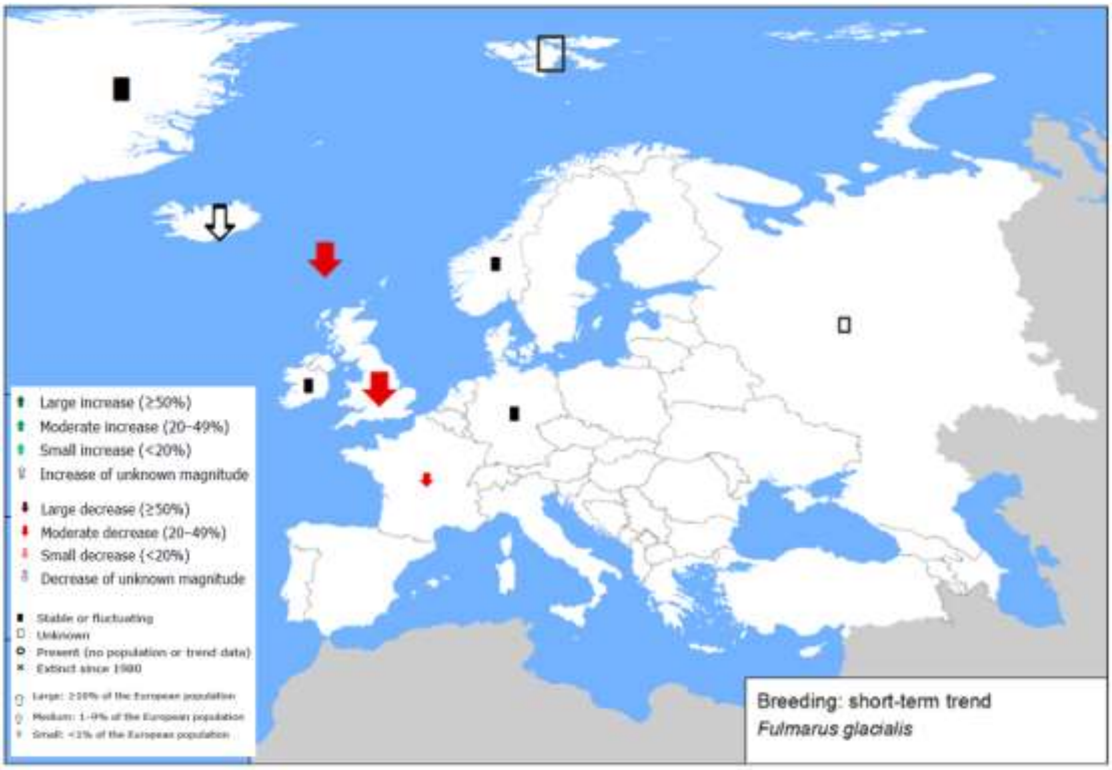

Figure 11: Northern fulmar population trends in the OSPAR area (source: BirdLife International (2015)

Thus, attempting to quantify population level trends for potentially impacted species is not a sound basis for assessing the actual risk or impact of a single factor such as the ingestion of or entanglement in plastic litter on the species studied. Since risk assessments are a combination of probability multiplied by severity, population impact or harm from plastic ingestion is therefore best represented by proxy data on frequency, quantity and types of plastic ingested, in combination with best available knowledge of the potential or likely harm caused by such ingestion.

It is certain that marine litter negatively affects a substantial number of individuals from a wide range of species. These clearly negative effects include physical harm and mortality from both entanglement in and ingestion of plastic litter. There are also studies demonstrating that even small quantities of marine litter can modify marine assemblages potentially compromising ecosystem services. The expert group considered it was highly likely that plastic ingestion and entanglement in marine litter does have population level effects on those marine species where a high proportion of individuals regularly ingested or were entangled in plastic litter. This is especially likely for many seabird species in the family of tubenoses and other seabird groups, many of which are red-listed by IUCN as well as all species of marine turtles which are frequently affected by physical encounters with plastics, so that population effects must be assumed.

Furthermore, although the relative importance of plastics as a vector in the transport of chemical contaminants to biota is still unclear and will be influenced by a number of factors including residence time in the organism, available evidence suggests that this aspect needs to be regarded as a potential additional mechanism of harm on biota. The circumstances under which potentially game-changing data become available might be too late for any policy intervention to be effective. To put this into context, awaiting population level evidence would be like not addressing smoking or obesity as a human health problem because the human race is not in decline.

Where it is not possible to numerically quantify the effect of marine litter on populations of a particular animal species, common sense in the form of the Precautionary Principle should guide policy. This can be done for example, by projecting the average quantity of plastics in stomachs of a Fulmar in the North Sea to the scale of a fulmar of human body mass. Fulmars roughly weigh 700 g, and currently have an average content of over 0.3 g of plastic. Scaled to a human body mass of about 70 kg, the average stomach content would be over 30 g of plastic. Although we lack quantitative scientific evidence of the scale of negative impacts of such stomach content, from its visualisation (Fig. 12), the common-sense decision is, that this amount of litter would be seriously unhealthy and negatively affect fitness of the individual, and thus the wellbeing of both Fulmars and humans.

Figure 12: Average plastic abundance in a Fulmar stomach and the human scale. The average content of plastic in stomachs of Fulmars from the North Sea is shown to the left of the tweezers, currently a bit over 0.3 g per stomach. To the right of the tweezers is the same average, but scaled to a fulmar of human body weight, which then reveals a considerable quantity of sheets, fragments, threads (top row), foams and industrial granules (bottom row) (source: Jan van Franeker –IMARES)

Since understanding risk requires data on both frequencies of encounter and severity of encounter it is clearly of importance to experimentally assess in more detail the lethal and sublethal, physical and chemical effects of plastic ingestion at the individual level. And to also include those data into models for estimating population level impacts. This will be a complicated and time-consuming process, however, and the absence of this data is not a reason to delay remedial action.

Marine litter also causes diverse and complex impacts on wildlife by degrading molecular, physiological and, ultimately, ecological processes. Evidence linking the different levels of impact of litter on the marine environment would assist in the design of surveys, population models and experiments, which aim to understand the effects of litter pollution on the marine environment. According to Browne et al. (2015) such linkages can only be explored by integrating evidence across biological scales in order to provide the understanding to guide assessments of risks and responses to ecological impacts of litter (Browne et al., 2015). Some examples of demonstrated linkages among levels of biological organization for effects of litter in organisms are already available. Lugworms ingesting micrometre-sized PVC showed increased oxidative stress with fewer antioxidants. In the case that the PVC contained triclosan reduced feeding and mortality was observed (Browne et al., 2013). Another study demonstrated the injury of digestive gland cells after ingestion of micrometre-sized polyethylene in mussels producing also more granulomas in gut-tissues than normally (von Moos et al., 2012)

For macro litter, experiments can e.g. provide the information necessary to model rates of catch, and therefore mortality, resulting from lost fishing gear. To estimate the ecological impacts on populations one has to go a step further and to carry out population modelling (Browne et al., 2015) in order to gain an overview of the total population and therefore put the losses associated with lost gear into proportion. Hence models and experimental settings must be constructed and designed in a way to determine whether populations are declining because of litter and which part(s) of the life cycle are being affected in order to gain a better understanding of the mechanism of impacts caused by marine litter.

2.8 Animal Welfare

As an underlying ethical aspect of the above mentioned biological impacts of marine litter the issue of animal welfare should not be neglected. From the perspective of the negatively affected individual animal, marine litter can be regarded as harmful and an impact on its welfare. So far animal welfare issues have not been considered in impact assessments of marine litter (CMS 2014). Unlike many societal challenges suffering caused by litter is not related to one single human activity, but to a broad spectrum of sea-based and land-based sources.

According to the European Union´s Lisbon Treaty, animals are recognised as sentient beings, meaning that they are capable of feeling pleasure and pain. However, the according rules on protection as laid down in the Council Directive 98/58/EC do apply to animals of commonly domesticated species and those under human control, as for example fish farming, only. However, one element which can be regarded as a common ethical principle to be generally applied to animals both, wild and tame, and which can be found in national legislations, concerns the provision to avoid any unnecessary suffering of animals. Animals which become entangled by, trapped in, or ingest marine litter often experience trauma, damage, infection and compromised ability to feed, move and carry out their normal behaviour. The resulting suffering and pain, creates a compelling argument that marine litter represents not only a serious environmental, conservation, human health and economic issue, but also as a significant global animal welfare issue that requires urgent action (Butterworth et al., 2012).

The term animal welfare refers to the physical and psychological wellbeing of animals and means how an animal is coping with the conditions in which it lives. Defining welfare involves more than simply looking at what an animal can endure or survive. Assessment of welfare considers the mental, physical and physiological condition of the animal. The welfare of an animal refers to the degree of well-being or suffering that the animal experiences. Well-being refers to a positive subjective state while suffering refers to a prolonged or actually negative subjective state. Well-being is threatened by, and suffering may result from, being subject to aversive stimuli or from being deprived of certain stimuli or behavioural opportunities. Assessment of an animal´s welfare is optimally conducted by combining behavioural data with physical and physiological data (Sweeney, 1990). Yet, the science of marine animal stress is relatively new, and marine species often exhibit behavioural indicators of poor welfare in ways that are not easily observable to humans. Furthermore, addressing the welfare or well-being of aquatic animals is a complex and challenging task for science since aquatic animals encompass extremely diverse, divergent and distantly related taxonomic groups of greatly varied phylogenic ages and linkages. They range from highly developed marine mammals to lower invertebrates, all with very different anatomies, physiologies and behaviours (Hastein et al., 2005). Sentience of fish species has been investigated and evidence to the effect of fear, pain and stress in fish has been found. Prolonged exposure to stressors can lead to chronic stress responses indicative of poor welfare including reduction in immune function, disease resistance, growth and reproduction, eventually dead (EFSA 2009). The major types of litter affecting marine animals cause problems for a wide range of species. The same items can cause a range of physical impacts, and these impacts can result in poor animal welfare experiences over a range of timeframes; acute impacts may cause suffering and distress for minutes while chronic impacts may cumulative, causing increasing suffering over periods as long as years. From the available literature, it does not appear that detailed information on injury type and welfare impacts is collected as standard by researchers investigating the impacts of marine litter.

To create a basis for sound assessment and decision making in order to address the welfare of marine animals, an extensive species and litter-type specific dataset need to be compiled to allow comparative scoring of welfare impacts in terms of severity and duration of suffering. This could be used in risk assessment frameworks in order to not only assess population impacts or conversational implications with respect to threatened species but also to take into account the unnecessary and avoidable suffering of marine wildlife.

3. Socioeconomic effects

3.1 Introduction

Marine litter is a pressure, not only to marine habitats and species, but also to ecosystem services, with important implications for human welfare, by impacting negatively on economic sectors such as tourism, fisheries, aquaculture, navigation and energy and bringing economic losses to individuals, enterprises and communities. Furthermore, given that litter can be transported over large distances, it may result in costs to areas that are far away from its point of origin and may place a burden on sectors that are not solely responsible for its generation.

Ideally, an economic analysis would compare the costs of measures to prevent marine litter with the economic damage and remediation costs. However, the limited and fragmented knowledge about the full extent of impacts on the environment and human welfare prevents such a consistent and systematic analysis (Brouwer et al., 2015). Furthermore, establishing the economic costs of marine litter is complicated by the wide variety of approaches available for valuing the environment and detrimental anthropogenic impacts. Despite these inherent limitations, there is a growing body of evidence on the negative externalities created by marine litter and also on the benefits of preventive actions towards minimising litter releases to the natural environment (e.g. Watkins et al., 2016).

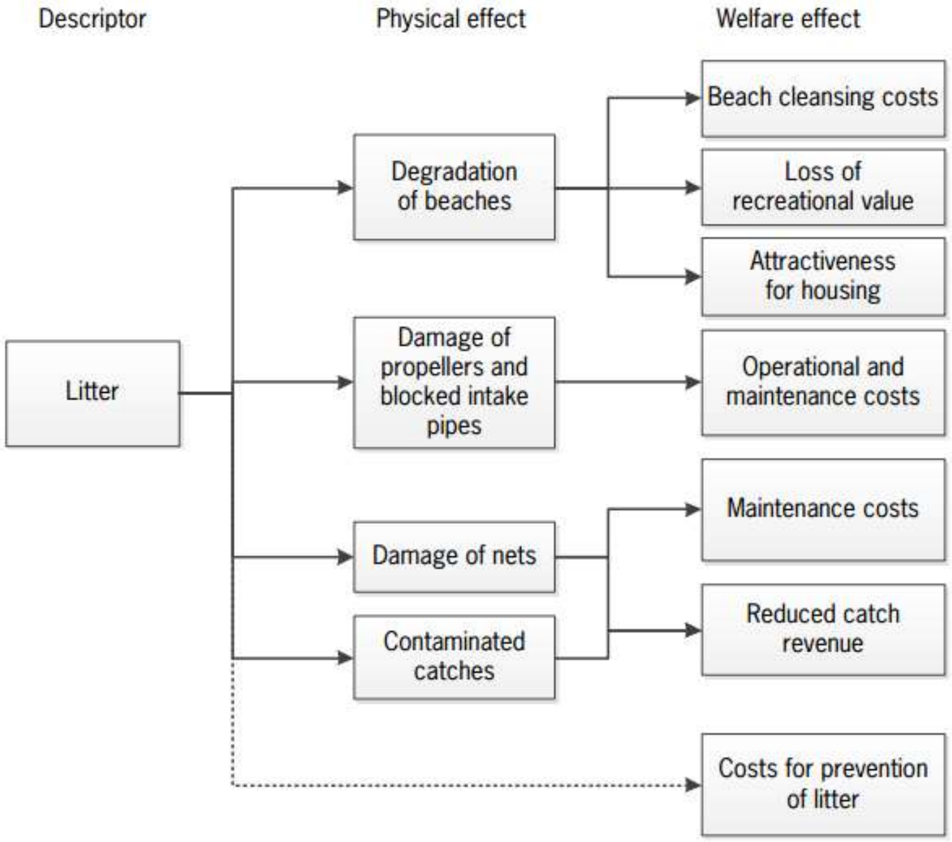

Figure 13: "Logical Diagram of Impact" for beach and marine litter on socio-economic activities (Source: Reinhard et al., 2012)

Although the main driver to prevent and reduce the amounts of litter in the coastal and marine environment is the protection of marine ecosystems and sustaining the services they provide, actions to tackle marine litter can also enhance resource efficiency within the production-consumption-treatment cycle and contribute to the implementation of a circular economy. As argued by Watkins et al. (2016), the significant value inherent in plastic that becomes marine litter or is landfilled represents an important opportunity for economies.

This section provides an overview of the potential implications of marine litter on different economic sectors and, whenever possible, available examples of estimated costs incurred on actions to address or mitigate its impacts, such as clean-up operations to ensure the amenity value for tourism and the functionality of ports and harbours.

3.2 Implications on maritime sectors

In recent decades, several studies have focused on the economic impact of marine litter to maritime activities such as shipping, fishing and fish/shellfish farming but only a few of these have attempted empirical research to estimate the costs incurred. The data is mainly based on smaller regional studies and on modelling, but it provides a snapshot of the kinds of costs arising from marine litter.

3.2.1 Impacts on fisheries and aquaculture

Marine litter can impact fisheries by reducing catches as a result of time taken removing litter from the nets and by damaging the catches themselves. Furthermore, additional time and costs are needed to repair damaged fishing gear. For other vessels, additional problems can arise from entangled propellers and obstructed cooling systems.

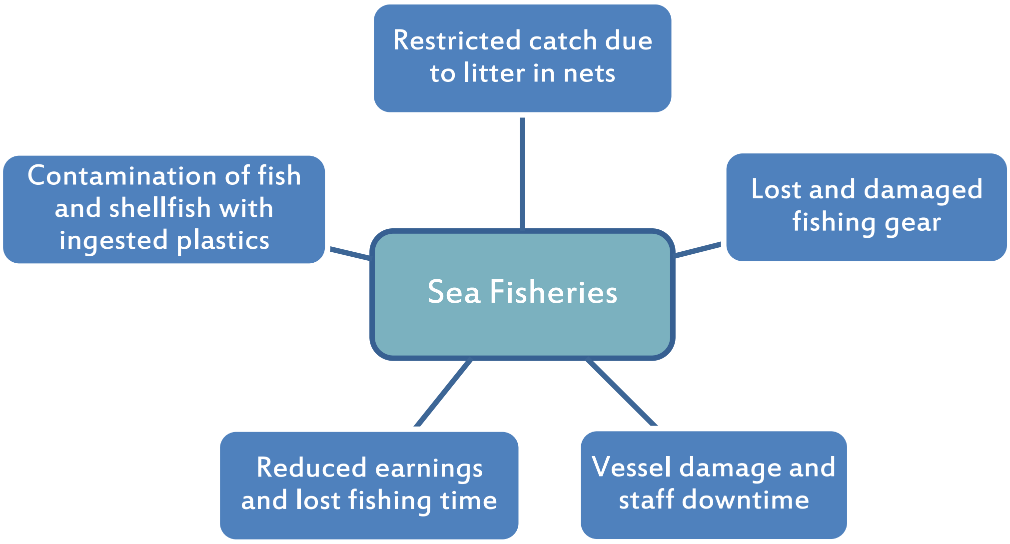

Figure 14: Potential impacts of marine litter on fisheries (source: adapted from Mouat et al., 2010)

With increasing evidence on the ingestion of plastics by marine animals, including commercially important species, contamination of fish and shellfish can have additional implications for fisheries and aquaculture. Van der Meulen et al. (2014) considered aquaculture of mussels and oysters as a case study to assess the potential risks of microplastics on the economic value of the shellfish industry. The authors conclude that there is a hazard of microplastics to the aquaculture sector due to overlap in the areas in which microplastics occur and where aquaculture is conducted. They projected a yearly loss of 0.7% of annual income every year for the sector arising from shellfish ingestion and associated biological affects and loss of sales revenue. Under high concentrations of microplastics, effects can be observed in mussels and oysters that could affect revenue. Despite there being little or no evidence of direct impacts on seafood production in terms of economic value or on human health, the presence of plastic in seafood may influence the acceptance of these products and potentially lead to economic losses as a result of a perceived risk by consumers (Van der Meulen et al., 2014; GESAMP, 2015).

Benefits of reduction of marine litter in fisheries in the Dutch North Sea

A study performed in 2012 interviewed a large number of individual fishermen, shipyards, and arbour authorities, as well as other relevant stakeholder organisations, to estimate the benefits of a potential reduction of marine litter in the Dutch part of the North Sea. Marine litter was reported to be an issue in terms of jammed propellers and damaged nets, in particular to smaller vessels operating closer to the coast. The total damage to fisheries on the Dutch continental shelf (including fisheries under foreign flags) was estimated to be around €2 to €3.5 million per year. To put this in perspective, it is estimated that the production value of Dutch fisheries in the Dutch part of the North Sea in 2015 is approximately € 100 million[1]. Taking into account the production value of fisheries under foreign flags, marine litter may cause damage in the order of 1% of total production value. This is in line with the European average. However, it is interesting to note, the impression of fishermen that the North Sea has become much cleaner in recent decades. (Ecorys, 2012).

At the European level, Acoleyen et al. (2013) estimated that for the active EU fishing vessels, the costs due to damage and losses reaches approximately €61.7 million (Table 5), equivalent to a reduction of nearly 1% of the total revenue generated by the EU fleet in 2010 (landed value of €6.6 billion[1]).

Table 5: Estimated costs of impacts of marine litter on fisheries and extrapolation to EU fleet (source: Acoleyen et al., 2013)

	Annual cost per vessel (€)	# vessels in the EU	Total annual cost EU (m€)
Cost of reduced catch revenue (trawlers)	2.340	12 238	28,64
Cost of removing litter from fishing gear (trawlers)	959	12 238	11,74
Cost of broken gear & fouled propellers	191	87 667	16,79
Cost of rescue services	52	87 667	4,54

Another issue that may pose a problem to the fishing industry, but so far has yet to be quantified in economic terms, is the effect of marine litter on selectivity grids used in bottom trawling. This kind of equipment will become more and more important with the implementation of the reformed Common Fisheries Policy and the necessary actions needed to reduce bycatch. A study in the north-eastern Mediterranean by Eryaşer et al. (2014) found that heavy accumulations of marine debris can block the grid, thus rendering them ineffective and potentially causing commercial losses to fishers. This was predicted by measuring the surface area of debris accumulated during trawls, but was also observed occurring in real-time during un-related studies on the functioning of these grids.

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[1] According to Member States DCF data submissions, the total amount of income generated by the EU fishing fleet in 2010 (excluding Greece) was €7 billion. This amount consisted of €6,6 billion in fish sales, €34 million in fishing rights rental income, €193 million in non-fishing income, and €126 million in direct income subsidies (JRC; 2012).

Costs to the Scottish fishermen

The results from a survey mainly among Scottish trawlers showed that ropes and plastic were the most frequently caught type of marine litter, with 90% of respondents finding these items. Bottles, wire, nets and tires were reported by 70% of respondents. Economic costs arose from litter accumulating in nets and thus reducing the amount of catch possible (reported by 86% of respondents). The study found that on average, the cost to each vessel in the Scottish fishing fleet from marine litter related incidents came to between €17 219 and €19 165 per year. The majority of this cost resulted from the loss of fishing time incurred due to clearing nets of marine litter, accounting for on average 66% of the total costs per vessel. However, as the study points out, the exact economic costs from time spent not fishing due to marine litter depends on the quality of the fishing at the time and location the incident occurs, and is therefore highly variable (Mouat et al., 2010).

ALDFG poses a particularly harmful category of marine litter and causes economic harm to fishermen in a variety of ways. Assuming gear was lost as opposed to purposely abandoned, this represents a significant cost to the fisherman in gear which must be replaced. The gear is likely to continue to ‘ghost’ fish as fish become entangled and killed, in turn attracting predatory fish to the net. This ghost fishing reduces fish stocks, and represents an unknown mortality rate when assessing fish stock health for sustainable fisheries management (Warden & Murray, 2011). Gear once lost also represents an additional snagging danger to bottom contact gear types, potentially leading to further gear loss (Macfadyen et al., 2009). An example of the kinds of economic harm to fisheries from ALDFG is demonstrated in the 2007 study by Brown & Macfadyen, who used modelling to assess the cost to a hypothetical EU gillnet fishery. Factoring in the cost of the net lost plus the loss of available fish from the stock arising from the ghost fishing of a single fleet of gillnets, €26,400 is lost to the fisherman. It is assumed that roughly one fleet of nets is lost per fishing boat per year, so this represents the yearly cost to a vessel (Sherrington et al., 2016).

Survey-based regional assessment of ALDFG and ghost nets in the Mediterranean

A UNEP/MAP survey-based regional assessment of ALDFG and ghost nets in the Mediterranean was conducted by MIO-ECSDE in 2015 interviewing some 560 fishermen, sailors, skippers, vessel owners, divers and other relevant stakeholders from 11 countries (Albania, Algeria, Croatia, Egypt, Israel, Lebanon, Morocco, Palestine, Syria, Tunisia and Turkey). Some 52% of respondents reported that they experienced either often or almost every time problems with marine litter caught in their nets. Furthermore, a large majority of the respondents (71%) considered the issue of ghosts nets a serious (42%) or moderate problem (29%). Almost half of the (47%) felt that ghost nets were a problem and similarly some 41% considered the impacts of ghost nets as serious ones. Regarding DFG it was very concerning to see that 37% of the respondents admitted to eventually dumping gear it on land (illegal dumpsites), since according to their views there are no specific collection points for DFG at ports or marinas. Regarding marine litter management practices on board and on shore it seems that there is a lot of room for improvement. A little less than 50% claimed to have no waste bins on board and some 38% admitted throwing litter back overboard. Around 40% of the respondents were not satisfied with the waste collection facilities back at ports, with accessibility being also a major issue

Economic costs from marine litter can arise for fishermen who wish to responsibly dispose of the marine litter and derelict fishing gear that they encounter during operations. The cost of port reception facilities can be high, especially for non-ship generated waste which is often subject to a direct fee (Øhlenschlæger et al., 2013). There are numerous schemes to encourage disposal of fished litter and to reduce the economic cost to the fishermen, including KIMO’s Fishing for Litter scheme[2] and the National Ocean and Atmospheric Administration (NOAA) Marine Debris Program’s Fishing for Energy, which provides free reception facilities for derelict nets and incinerates them for energy. The KIMO scheme in Scotland reports a cost of 1000 €/T of marine litter

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[2] Voluntary initiative in which fishermen bring ashore marine litter that was accidently caught in nets during normal fishing operations (http://www.kimointernational.org/FishingforLitter.aspx)

retrieved, with 242 tonnes retrieved in the period 2008-2011. These costs were not born by the fishermen but by the organisation itself (KIMO, 2011) and include other activities that are not associated with the direct collection of marine litter. A recent UK survey of this scheme demonstrated some wider benefits with fishers participating in the scheme self-reporting a higher level of waste management on their vessels when compared to fishers not in the scheme (DEFRA 2016).

Valuable insights on the socio-economic implications of marine litter on aquaculture, among other targeted sectors (tourism, fishing, navigation) in the Adriatic-Ionian macroregion are provided by a recent study carried out within the framework of the IPA-Adriatic funded DeFishGear project (Vlachogianni, 2016). The results from the survey-based study carried out in six countries, namely Albania, Croatia, Italy, Greece, Montenegro, Slovenia showed that the average annual direct and indirect marine litter related costs for the aquaculture sector were assessed to be some € 3,228 per aquaculture farm unit. The average amount reported for Montenegro was 500 €/year, for Greece 1,888 €/year, for Albania some 2,146 €/year, for Croatia 2,352 €/year, while for Italy the costs reported where much higher reaching some 15,000 €/year. In comparison to the average cost of marine litter to aquaculture producers recorded at 580 € per year in Scotland (Mouat et al, 2010), the costs assessed in the Adriatic-Ionian macroregion were considerably higher. The total costs for the aquaculture sector in the region were difficult to be estimated, however given the large-scale operations of this sector the overall costs seem to be of substantial magnitude. In general, the majority of costs were incurred because of: loss of time due to clearing litter from the farm facilities (989 €/year); costs for divers to clean facilities or to un-foul boat propellers (803 €/year); cost of new equipment and facilities (663 €/year); loss of revenue due to spoiled livestock (541 €/year); costs of repairs due to marine litter (200 €/year); cost of injuries due to marine litter (32 €/year).

3.2.2 Impacts on shipping and ports

There is limited large-scale information available on marine litter related incidents rate or the economic cost to the shipping industry from marine litter. Nevertheless, the kind of issues marine debris poses to vessels is well known from more localised studies, as shown in Figure 16.

Figure 15: Potential impacts of marine litter on shipping industry (source: Mouat et al., 2010)

Mouat et al. (2010) surveyed harbours and mariners in the North East Atlantic region to ascertain the costs faced from marine litter. Over 71% of harbours and marinas surveyed in the UK reported that their users had experienced incidents such as fouled propellers, fouled anchors, fouled rudders and blocked intake pipes and valves. The most common incidences in surveyed harbours were: 69% reported fouled propellers, 28% blocked intake valves and pipes, 13.2% fouled rudders and 7.7% reported fouled anchors. Fanshawe (2002) included snagged dredging gear among the direct impacts of litter on maritime activities.

Costs for the Dutch Fleet in the North Sea

According to a study focused on the Dutch area of the North Sea (Ecorys, 2012), the size of the vessels appears to be an important factor determining the scale of potential damage due to marine litter, with larger ships being less vulnerable e.g. to entanglement of propellers. Interviews of fishermen and boatmen could not pinpoint particular hotspots of litter in the North Sea although the majority indicated a greater risk for damage due to litter in shallow areas such as rivers, river mouths and port areas.

The total damage that the Dutch shipping fleet experienced as a result of litter at sea within the Dutch Continental Shelf was estimated to be between € 1.5 and € 4 million per year. Based on the same assumptions as for fishing, the maximum benefits for shipping, given a 50% reduction in marine litter, are estimated to be between € 1 and € 2 million per year. Considering that the estimated production value of Dutch shipping in the Dutch part of the North Sea in 2015 was approximately € 3,134 million1, the damage caused by marine litter is less than 1% of the production value.

The total cost of removing marine litter reported by 34 harbours in the UK was approximately €273 000 with an average cost of approximately €8 000 per harbour per year.
Based on this average, the authors estimated that marine litter costs the ports and harbours industry in the UK approximately €2.4 million each year. It can be assumed that a significant part of these costs are passed on to harbour users through harbour dues (Mouat et al., 2010).

Looking further afield for evidence of harm to shipping activities from marine litter, McIlgorm et al. (2009) found that damage to Hong Kong's high speed ferry services from marine litter amounted to US$19 000 per vessel per year. The same study estimated that the value of damage to shipping industry in the APEC region is US$279 million per annum, however this figure must be treated with caution considering the lack of data on the issue.

Harm to sea-users from marine debris is little reported, however at least one incident of a vessel sinking as a result of debris entanglement has been reported, resulting in significant loss of life. The Korean Maritime Accident Investigation Agency reported that the 110 GT Ferry M/V Soe-Hae sinking in 1993 was caused in part by fishing ropes around the propellers, causing 292 deaths (Cho, 2005).

By investigating the various examples of harm to shipping, it is evident that there is significant economic damage to the sector from marine litter, however due to the current lack of data, quantification of the problem at an EU level is difficult. Care should be taken when conducting cost benefit analysis of debris removal or prevention activities to ensure that the economic harm to this sector is not overlooked due to lack of data.

3.2.3 Clean-up costs of floating or seafloor litter

Targeted clean-ups of floating marine litter or litter deposited on the sea-floor is restricted to a scattered but increasing number of initiatives and programmes, which are, in most cases, voluntary-based or funded by private entities.

For example, Project AWARE estimates the value of Dive Against Debris^{TM} - an underwater litter removal and reporting programme that relies on volunteering scuba divers – at 20 €/person/hour for recreational scuba professionals and about 8 €/person/hour for non-professional scuba divers. An average size event, including preparation, conduct and data reporting is estimated to take about five hours and include anywhere between two and a 100 volunteers.

Cleanup costs for harbours – Port of Barcelona (Brouwer et al., 2015)

The Port of Barcelona is and among the five biggest cargo ports in the Mediterranean and one of the most important ports for cruises in Europe, receiving over 3 million cruise and ferry passengers annually. The concentration of marine litter found inside the port of Barcelona was estimated to be 20 times higher than the average found in the Mediterranean as a whole. Due to its strategic location, being well integrated in the city and open to tourists and citizens, its infrastructure and its use, the port represents a large receptor of waste, related to both sea-based sources and the dynamics of the surrounding urban environment.

Clean-up of the floating litter inside the port of Barcelona is conducted daily throughout the year. In 2012, over 117 tonnes of floating litter were collected and the port authorities reported that the annual cost of collection was approximately €300,000. Probably because of the location and dimension of the port of Barcelona, these costs are relatively high when compared to the costs reported in Mouat et al., (2010) for ports in UK (€ 8,035 per port per year) and the nine Spanish ports surveyed in the Atlantic (€ 61,015 per port per year). Finally, this study estimated saving costs of approximately 12% (€37,000 per year) considering a scenario in which policies targeting two very common items removed (fish boxes discarded by fishermen and plastic bottles discarded by tourists) lead to significant reductions in the occurrence of these items as marine litter (Brouwer et al., 2015).

3.3 Impacts on coastal communities and tourism

Probably the most conspicuous impact of marine litter, frequently visible to beach visitors surveyed in Europe (Hartley et al., 2013), arises when it is deposited on the shoreline through the action of tides and winds. Litter has obvious impacts on the aesthetic value and recreational use of coastal areas, being a discouraging element for visitors and tourists and leading to loss of revenues for related services or significant costs incurred in clean-ups to maintain the areas attractive (Fig. 17). This section discusses the aesthetic value of clean beaches for tourists (3.3.1) and the costs of beach clean-ups (3.3.2).

Figure 16: Potential implications of marine litter on coastal municipalities (source: Mouat et al., 2010)

3.3.1 Reduction of aesthetic value and beauty of the coast

Some of the economic costs to coastal municipalities include the direct costs of keeping beaches clear of litter and its wider implications for tourism and recreation (Watkins et al., 2016), as illustrated in Figure 18.

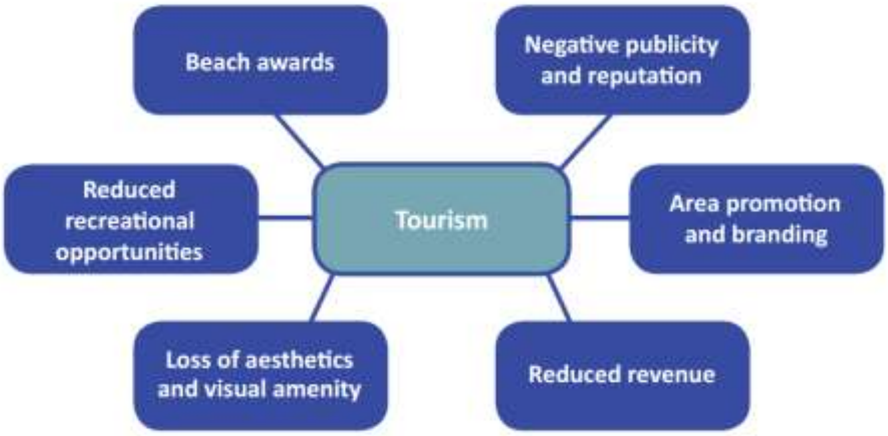

Figure 17: Potential impacts of marine litter on coastal tourism (source: Mouat et al., 2010)

Eftec (2012) conducted an extensive literature review to collect all the information available on the recreational value of having less litter in the marine environment. In total 458 studies referenced to the recreational value of less litter in the marine environment but only 44 of these represented original studies. Relatively few economic valuation studies were found in the literature review and evidence on the local economic impact due to changes in litter (and associated changes in visitor numbers) was limited. Despite the lack of quantitative evidence, it is undisputable that litter affects the aesthetic value of coast and it can be assumed that it can lead to changes in visitor numbers and consequently visitor expenditures.

In 2012, a short survey was conducted among visitors of a "Holiday Fair" in the Netherlands (data not published), in which participants were asked to prioritise a series of sustainability related aspects when choosing a coastal holiday destination. In total, 423 visitors responded to the survey and have indicated reduced levels of litter in the beach and the sea as the 3rd most important criteria among the provided list, while a good performance on waste management and recycling was also deemed important (Fig. 11).

Issue	*Priority (1-10)*
HUMAN RIGHTS OF LOCAL PEOPLE ARE RESPECTED	9
THE **SEA WATER IS CLEAN** AND SAFE FOR SWIMMERS	8.9
NOT MUCH **LITTER** ON THE BEACHES NOR IN THE SEA	8.8
NATURE AND WILDLIFE IS WELL PROTECTED	8.7
CULTURAL HERITAGE IS WELL PROTECTED	8.4
GOOD **WASTE MANAGEMENT** AND RECYCLING	8.1
LOCAL MARKETS, **TRADITIONAL** FESTIVALS	8.1
MAXIMUM APPLICATION OF **SOLAR ENERGY**	8.1
FOOD: **TRADITIONAL DISHES**, USING LOCAL PRODUCTS	8
MY HOTEL HAS A **ECO-LABEL**	7.3
MANY **WIND TURBINES**, EVEN IN THE MOUNTAIN	6.6
WIND TURBINES IN THE SEA	6.2

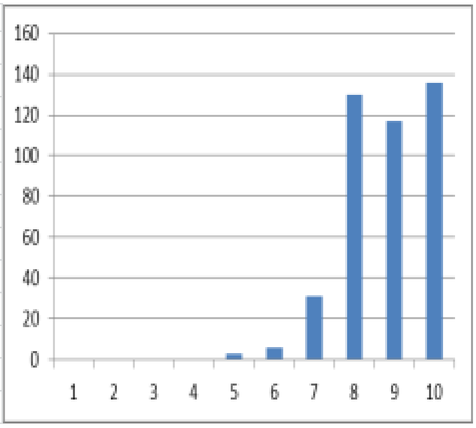

Figure 18: Results of a survey conducted in a Holiday Fair in the Netherlands (EUCC, 2012 – data not published) in which respondents were requested to score (1-10) the different sustainable management criteria when choosing their coastal holiday destination. Left- average total scores attributed to the different criteria; Right – distribution of individual scores given to "Not too much litter on the beaches nor in the sea".

More recently, a study carried by Brouwer et al. (2015) to estimate the social costs of beach litter in three different regions in Europe, based on the willingness to pay (WTP) in relation to beach litter. 650 visitors at six different beaches in Greece, Bulgaria and the Netherlands were interviewed, using the same discrete choice experiment. The study assessed beach visitors' perceptions in relation to beach litter, and their willingness to contribute in kind (volunteering to clean up beach litter a number of hours per year) and in money terms by paying either an entrance fee or an increase in local tax. The WTP value is directly related to the welfare loss experienced by beach visitors as a result of the presence of beach litter and therefore used as an indicator of the social cost.

This study provides an indication of the value that people attribute to a litter-free beach. As expected, the more littered a visitor perceives the beach and the more he/she is annoyed by it, the more likely he/she is willing to contribute to clean-up actions and also paying an entrance fee or increase in local tax. Compared to the beach visitors' average annual income levels, the estimated WTP values are highest in Bulgaria, where people are prepared to pay 0.07% of their income, compared to 0.01% in the Netherlands and 0.003% in Greece.

Aesthetic value of beaches and Willingness to Pay (WTP) to keep litter-free beaches in the Netherlands, Greece and Bulgaria

The presence of beach litter is considered very annoying to 31% (beach visitors in the Netherlands) and 91% (beach visitors in Greece) of interviewees involved in the study. Beach litter was also indicated as a reason not to visit the beach by 44% (Greece) and 95% (Bulgaria) of respondents. Beach visitors in Bulgaria and Greece value more the cleanup of items such as plastic and cigarette butts than of fishing nets, while in the Netherlands respondents value removal of all types of litter equally.

Bulgarian and Dutch beach visitors significantly value a reduction in the amount of litter from the current situation to less or no litter at all. Furthermore, having no litter on the beach is valued significantly higher than reducing the amount of litter to less than average (10-30 litter items per 100 m2). The origin of litter also seems to matter for the Bulgarian and Dutch respondents, as their WTP is significantly higher for litter left by visitors than deposited on the shore by the sea.

WTP were adjusted with differences in purchasing power across the different countries and two different values (€/household/year) were estimated:

1) Mean WTP for complete removal of plastic litter washed ashore: Greece - 0.67; Bulgaria - 8.25; Netherlands - 2.05), and

2) Mean WTP for removal of cigarette butts left behind by beach visitors: Greece – 0.42; Bulgaria – 7.06; Netherlands – 2.57 (Brouwer et al., 2015)

3.3.2 Costs of beach cleaning

Litter that is removed from the coast derives either from beaching of sea floating litter (marine litter) or is for example left behind by beach users. In this sense, and depending on the location, beach cleanup can be seen as a preventive (if it removes recently produced litter that would otherwise be washed into the sea) and remediation action (if it removes litter that was already present in the marine environment).

Direct costs of beach cleaning include the collection, transportation and disposal of litter, and administrative costs such as contract management. In addition, it should be noted that voluntary organisations also often play a significant role in litter removal, and that some value should be attributed to volunteers' time (Watkins et al., 2016).

To date, there has been no systematic analysis carried out regarding the current levels of spending by local, municipal, regional or national authorities on beach cleaning across Europe. Furthermore, there is no standard approach to waste management on beaches. There are large differences between coastal municipalities in how they have organized their waste management, which parties are involved, and who is responsible for waste facilities and beach cleaning. Estimates thus rely either on trying to compile data from sub-national authorities in order to build up national estimates, or to extrapolate on a per kilometre basis the cost of such activities. These estimations can fail to capture all relevant authorities and leave out costs that may not be under the remit of the same authority. Furthermore, the costs vary considerably depending on the location, the type of beach (e.g. rocky or sandy) and the intensity of use (e.g. for bathing and other tourist activities) (Acoleyen et al., 2013).

For example, in the Netherlands, a study was performed to estimate the costs of beach cleaning along the Dutch coast (Ecorys, 2012). Detailed information was collected through a combination of desk research supplemented by interviews in a representative sample of 16 (out of 28) Dutch coastal municipalities, complemented with some beach pavilion holders and members of interest groups (Tab. 6).

Table 6: Estimated beach clean-up costs for the Netherlands (source: Ecorys, 2012)

Basis for Estimation	Average cost per unit (€)*	Total of units for the Netherlands	Total Annual costs for the Netherlands (€ Million)
1) Cost per km beach	15 800	336 km	5,3
2) Cost per ha beach	3 700	3.300 ha	12,2
3) Cost per km recreational beach	55 000	70 km	3,9
4) Cost per 1.000 visitors	90	40,8 million visitors	3,7
5) Cost per Municipality	176 000	28 Municipalities	4,8

* Calculations by Ecorys based on information from interviews

As an outcome of the DeFishGear project (Vlachogianni, 2016), the total cost of removing beach litter reported by the 32 municipalities located in the seven countries of the Adriatic-Ionian macroregion was estimated at € 6,724,530 per year, with an average of € 216,920 per year per municipality. On average the municipalities spent some 5% of their budget for marine litter cleanup operations.

In its Impact Assessment accompanying the proposal for reviewing the European Waste Management Targets,[3] the European Commission outlined the costs per kilometre for cleaning across a wide range of beaches, using data from a number of sources (Tab. 7).

Table 7: Beach cleaning costs from available studies (adapted from Acoleyen et al., 2013; sources: Mouat et al., 2010; Reinhard et al., 2012; Ecorys, 2012)

Beach type	Cost per km (€)	Year of data	Location	Sea[4]
Bathing	34 450	2010	Touristic beaches NL & B - 10 municipalities	NS
	28 320	2010	Touristic beaches; NL 6 municipalities	NS
	38 190	2010	Spain: bathing beach	MED
	31 796	2010	Portugal: bathing beach	ATL
	55 000	2012	Netherlands: recreational beaches	ATL
Non-bathing	214	2010	Sweden, non-bathing beaches	BAL

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[3] http://ec.europa.eu/environment/circular-economy/

[4] NS: North Sea; MED: Mediterranean Sea; BAL: Baltic Sea; ATL: Atlantic Ocean;

Beach type	Cost per km (€)	Year of data	Location	Sea[4]
Bathing & non-bathing	372	2010	Denmark, non-bathing beaches	NS
	15 800	2012	Netherlands	ATL
	7 150	2010	UK, also cleaning of less touristic beaches	NS
	3 750	2012	Latvia (Riga) bathing & non-bathing beach	BAL
	11 000	2007	NL: average total coast length	NS
	8 278	2010	Portugal: bathing & non bathing beach	ATL

Though we should be wary of the comparatively small sample size, it is clear that there is very wide fluctuation in the costs between bathing and non-bathing beaches, as well as between countries. In trying to estimate the costs of marine litter clean-up at the European level, Acoleyen et al. (2013) estimated that cleaning costs for the more than 50,000 kilometres of EU coastline amounted between approximately 194 and 630 m€ (see also Tab. 8), assuming that all beaches would be cleaned.

Table 8: Estimation of annual beach cleaning costs for the total coastal length of specific European countries and for Europe

	Cost per km of beach (€)	Total cost per country (m€)	Sources
UK		18	Mouat et al., 2010
Netherlands	15 800 – 55 000	3,9 – 5,3	Ecorys, 2012
Germany	3 083 – 65 000		Holzhauer, 2016
EUROPE	3 828 – 12 446	193,70 – 629,78	Acoleyen et al., 2013

Finally, voluntary initiatives of beach clean-up also remove significant amounts of litter from the European coastline and although these efforts do not represent direct economic costs, they reflect substantial resources in terms of time and man-power.

3.4 Perceptions of society about marine litter

The *Science in Society* Project MARLISCO[5] (2012-2015) conducted an extensive survey in 15 European coastal countries, targeting key sectors and the general public, in order to assess their perception for the problem of marine litter and the responsibility everyone holds. More than 3500 respondents took part and an analysis of the results (Hartley et al., 2013) indicates a high concern on the issue of marine litter, that it represents a problem not only for coastal communities and that the impacts on the marine environment and the appearance of the coast are the issues that raise more concern (Fig. 20).

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[5] MARLISCO – *Marine Litter in Europe Seas: Social Awareness and Co-Responsibility*. www.marlisco.eu

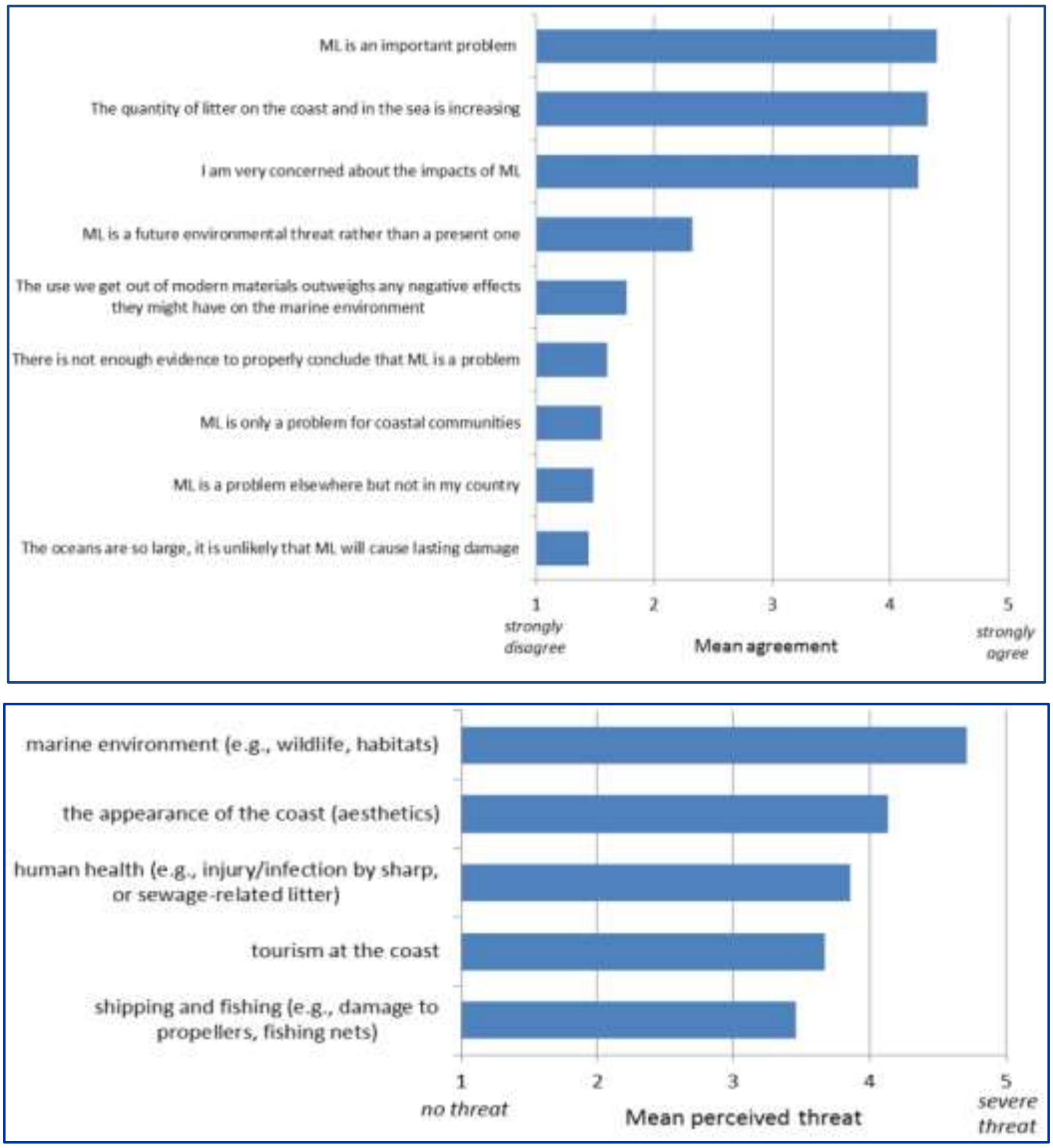

Figure 19: Results of stakeholders' survey conducted in 15 countries, involving over 3500 respondents on the concern of marine litter (top graph) and the perceived importance different threats and impacts (bottom graph) (taken from Hartley et al., 2013)

By contrast a survey of Dutch citizens (TNS-NIPO, 2011) found health care, employment and income more important than environmental issues. Only 5% of the respondents mentioned the environment as the most important issue. Within the various environmental themes, tackling pollution and depletion of the North Sea was considered less important than climate change and air pollution, but more important than improving water quality and the protection of forests and heathland. However, the survey also showed that when people were asked explicitly, they thought that litter was an important topic with half of the respondents being willing to pay a financial contribution to the solution of environmental problems. At the same time, when the following alternative measures were proposed, 1) an increase in taxes to be able to have more monitoring controls and cleaning programs 2) a price increase for products that contain plastics, or 3) no longer having the opportunity to receive plastic bags and sachets in stores, citizens overwhelmingly choose for not providing plastic bags.

A recent study by Wyles et al. (2015) showed that relatively small quantities of marine litter could have negative effects on the perceptions of coastal visitors. Marine litter was shown to reduce the restorative value that would normally be gained from a visit to the seashore. Interestingly the presence of packaging related debris was perceived as having a stronger negative effect than the presence of fishing related debris, probably because the accumulation of packaging was regarded as being more avoidable and hence unnecessary. Also, litter on beaches and at sea is often associated with waste issues and may be considered as a hygiene problem.

3.5 Human health risks

Marine litter, beached or floating, is considered a public health issue (Sheavly and Register, 2007; Galloway, 2015). Beside the risks to humans associated with propeller fouling and blocked intake pipes that are regularly reported in European waters (see section 3.2.2), large sized debris may typically affect humans from a molecular (toxicity) to an individual level. Pieces of glass, metal fragments, discarded syringes and medical waste may harm beach users. In some areas, up to 4% of injuries by needles are observed on beaches (Anonymous, 2012). Evaluating harm is however difficult as most incidents are unrecorded and measures such as cleaning, regulations and public information may limit associated risks. An investigation in Tasmania quantified risks for human injuries even at relatively clean beaches, finding 21.6% of beach visitors being injured, with 65% of the incidents resulting in wounds. 12.9% of the beach visitors perceived the possibility of injuries through beach litter as a major concern (Campbell, 2016). Entanglement can also pose a threat to swimmers, and divers who can become entangled in submerged or floating debris such as fishing nets and ropes. Even though uncommon, this is reported for monofilament nets (Mouat et al., 2010). Significant loss of life resulting from ship damage by propeller entanglement has been recorded at least once (see section 3.2.2), and incidents of injury to maritime workers may be much higher, considering the frequency of coast guard call outs and ship maintenance works arising from blocked intakes, entangled propellers or collision with larger debris items.

Because of the toxicity of some of their components to humans, especially plasticizers and additives, (Flint et al., 2012; Oehlmann et al., 2009) and because of the possible leaching of harmful chemicals (Thompson et al., 2009; Andrady, 2011), plastics may be considered as a potential hazard. To date, concentrations of toxins at sea remain very low (Flint et al., 2012) and may not be relevant in terms of chronic contamination. The risk to human health may however be more important when considering accidental inputs of debris with high presence of toxic compounds or harmful debris. For example, in 1993, four containers were lost from the SHERBRO in the English Channel, releasing 188 000 plastic sacks of pesticides. These washed up on the French, Dutch, Belgian and German shorelines (Mamaca et al., 2009). In another example, up to 23 000 explosive items lost in the Atlantic have washed ashore, often entangled in seaweed, resulting in a ban to fishermen, strollers and shellfish gatherers all the way from Brittany down to Spain.

The presence of microplastics in food could potentially increase direct exposure of plastic-associated chemicals to humans and may present an attributable risk to human health. The risk of chemical contaminants being transferred to humans depends on i) the retention time of particles in seafood, ii) the rate and degree to which contaminants are released from plastics, iii) the degree to which fine particles might be translocated from stomach of seafood to other tissues, and iv) the degree to which chemical contaminants can transfer from the consumed seafood to the human body (UNEP, 2016a). Fish, also shellfish for human consumption have been reported to contain micro particles, in particular fibres (Rochman 2016). However, microplastics are mostly present in the stomach and intestines (digestive glands and tracts), which are usually removed in large fish before consumption. It may be of concern for consumption of crustaceans, bivalve mollusc like oysters and mussels or small fish which are eaten entirely with the digestive tract (Cole et al., 2011). EFSA estimated the average intake for a portion of mussels (225 g) could contain 7 microgram of microplastic (EFSA, 2016). Currently no data is available for nanoplastics in food and toxicity data are lacking for both microplastics and nanoplastics (EFSA, 2016). However, according to UNEP (2016a), on the basis of current evidence, the risk to human health appears no more significant than via other exposure routes. This assumption is backed up by a conservative assumption by EFSA that the presence of microplastics in seafood would have a small effect on the overall exposure to additives and contaminants (EFSA, 2016).

The introduction of plastic debris, both micro and macro, into the ocean environment has greatly increased the amount of rafting material and consequently increased the opportunities for the dispersal of many and diverse marine organisms. Marine litter is now an abundant substrate for microbial colonization, physically and chemically distinct from natural substrates, it could support distinct microbial communities. From evidence for ecological impacts of plastic debris on microorganisms, mainly the colonization and survival on polymers by bacteria (Harrison et al., 2011), the question of transport of pathogens has now become crucial and may potentially support impact on human health (Zettler et al., 2013). While this potential impact is recognized, even recent literature (Keswani, 2016) reviewing harm to human health by microbial pathogens on plastics, highlights the needs for further investigation in order to assess the risk.

3.6 Effects of marine litter on ecosystem services

Commonly ecosystem services are classified into four main categories (MEA, 2006; Saunders et al., 2010): Provisioning services (e.g. generation of resources used as food and fuel); Regulating services (e.g. regulation of air quality, control of pests and diseases); Cultural services (e.g. spiritual/artistic inspiration); and Supporting services (e.g. photosynthesis, nutrient cycling). The focus for this analysis is whether effects on ecosystem services occur. We cannot presently quantify how serious/widespread any impact is, such quantification may be possible as the knowledge of quantities, distribution and mechanisms of marine litter improves e.g. through monitoring and research as a response to the MSFD.

There are many forms of ecosystem goods and services that are not explicitly listed in the table below (see e.g. different classifications in Saunders et al., 2010). In this report, we only include services where we consider it currently is possible to conduct a meaningful assessment. Services that we have not included may or may not be impacted by marine litter.

Table 9: Summary of assessed impacts of marine litter on ecosystem. Documented effects - empirical evidence on impacts from marine litter on the service; Probable effects - empirical evidence for conditions/mechanisms that probably leads to impacts on the service; possible effects - it is possible that the impact could occur

Category	Type of service	Level of confidence	Relevant chapters
Supporting	Biogeochemical cycling	Possible	2.4
	Food web dynamics	Possible	2.3.1; 2.4
	Primary production	Documented	2.6
	Biodiversity	Documented	2.6; 2.7
Regulating	Water flows, flood protection	Probable	
	Pest and disease control	Probable	2.5; 3.5
Provisioning	Food	Documented	2.3; 2.4; 3.2.1; 3.5
	Materials	Probable	3.2.1
	Energy	Probable	3.2.2
	Space and waterways	Documented	3.2.2
Cultural	Aesthetic values	Documented	3.3.1
	Recreational values	Documented	3.3.2
	Science and education	Possible	

4. Risk approach

4.1 Background

Formal risk assessment provides a structured process to inform judgements about the risks posed by an activity or various activities (marine litter is caused by manifold sectors/sources) and their significance. After problem framing and conceptual model development (including identifying the hazards associated with the activity/the activities under consideration), risk assessment involves four stages: (1) Assessing the potential consequences should receptors be exposed at a particular level (hazard identification/characterisation); (2) Assessing the exposure level i.e. the probability that a hazard will be realised (including the relevance of different pathways); (3) Characterising the risk (i.e. combining hazard and exposure) and (4) Evaluating uncertainty (at all stages of the process) (Fig. 12).

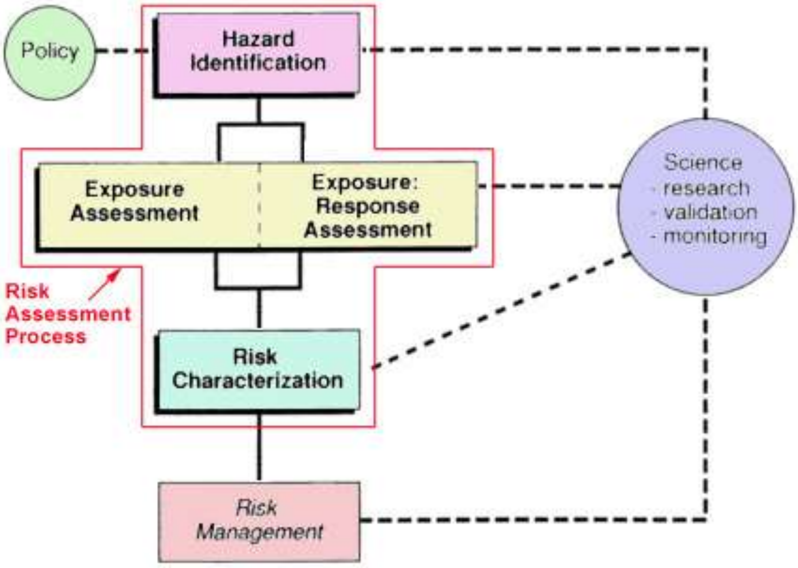

Figure 20: Risk assessment scheme as applied by the EPA's Office of Solid Waste and Emergency Response (EPA, 1992)

Most environmental risks are spatially and temporally limited, so a critical early need is to establish the risk of what is happening to whom (or which part of the environment), where (location) and when (in time). Framing the problem in clear and unambiguous terms will assist in selecting the level and types of assessment methodology used and ultimately improve the risk management decision. Development of a conceptual model can help to present in visual or written form the hypothesised relationships between the source (S) of a hazard, the pathways (P) by which exposure might occur and the receptors (R). The S-P-R relationship conceptualises which receptors could be at risk of exposure to the hazard under consideration and allows the strength of the link between hazard source and receptor exposure to be evaluated (the pathway). Risk screening can be used to identify what should or should not be investigated in more detail, while risk prioritisation typically provides a list of main concerns for further action. Both screening and prioritisation facilitate the effective allocation of resources. This process, whereby the problem is formulated and scoped, may need to be revisited as the assessment proceeds. The evidence required to perform the risk assessment can be qualitative, quantitative, or semi-quantitative. Where data are missing or inaccessible, formal elicitation can help to provide expert judgement. Uncertainty is always present at each stage of an environmental risk assessment. Various techniques exist to analyse, understand and employ uncertainty at each stage. Several key definitions pertaining to environmental risk assessment and management can be found in Annex II to this report.

4.2 Risk assessments for marine litter

The Marine Strategy Framework Directive (2008/56/EC) requires EU Member States to devise measures against, among other issues, harm caused by marine litter. Actions should be based on the precautionary principle and the principles that preventive action should be taken, that environmental damage should, as a priority, be rectified at source and that the polluter should pay. It should be ensured that there are no significant impacts on, or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea. These provisions require the identification, quantification and prioritization of risks. This includes also the identification of significant versus non-significant risks, the societal agreement on acceptable risks level and thus the introduction of quantitative evaluation criteria. While there is longstanding experience of environmental and human risk assessment, e.g. for chemical contaminants, such approaches for marine litter are currently under development. General risk assessment frameworks and guidelines exist and can support the development of such schemes (Gormley, 2011).

Taking into account the outline and guidelines listed above, a first risk assessment of marine litter and plastics should be completed to indicate where potential harm from marine litter might occur. Although as this report shows, some information might be missing (e.g. availability of precise numerical data for litter, including sizes and types of litter, exposure and impact description), data gaps can be filled by adhering to existing approaches and test guidelines or expert judgement. Developing a risk approach for marine litter will have to rely on proxies, elements with high uncertainty, partly on practical common-sense assessment approaches and on sound evaluation of related animal welfare implications. While it is important to recognise and describe such limitations alongside the conclusions of the risk assessment, this approach will allow for an assessment of the impact as a result of exposure to marine litter and plastics items, focus the science and ultimately should lead to more complete understanding of the issue.

See an example in Annex 1, where elevated risk for entanglement were attributed to the litter categories of the EU TG ML master list for monitoring (Galgani et al., 2013). It is clear that closed loop ropes, strings or bands and nets pose a high risk of entanglement, while e.g. containers could still entangle an animal but are much less likely to do so. In addition to entanglement and ingestion, the exposure will not only be defined by the abundance of litter items in the environmental matrix and the whereabouts of the animals, thus depending on their potential encounter, but also on an assessment of the potential harmfulness of litter items. The potential impact depends on the nature and shape of the litter items, including its alteration by physical degradation, versus the habitat use and behaviour of marine animal species. Furthermore, external factors such as wave action, visibility, etc. can play a role. Such an approach, applied to the different litter harm categories should be applied and enable an initial evaluation of risks in support of decision making.

4.3 Examples of marine litter risk assessments

With the rapid increase in global plastics production and the resulting large volume of litter that enters the marine environment, determining the consequences of this litter on marine fauna and ocean health has now become a critical environmental priority, particularly for threatened and endangered species. However, there are limited data about the impacts of litter on marine species from which to draw conclusions about the population consequences of anthropogenic litter as has been shown in this report.

Although a large number of empirical studies provide emerging evidence of impacts to wildlife, there has been little systematic assessment of risk (Galloway and Lewis, 2016). Some risk assessments for marine litter have been published for specific types of biota. Schuyler et al. (2014) investigated whether plastic litter ingestion prevalence in marine turtles has changed over time, what types of litter are most commonly ingested, the geographic distribution of litter ingestion by marine turtles relative to global litter distribution, and which species and life-history stages are most likely to ingest litter.

It is often unclear what the ecological threats to marine biota exist at a population level. To address this knowledge gap, Hardesty et al. (2016) elicited information from experts on the ecological threat (both severity and specificity) of entanglement, ingestion and chemical contamination for three major marine taxa: seabirds, sea turtles and marine mammals. The threat assessment focused on the most common types of litter that are found along the world's coastlines, based on data gathered during three decades of international coastal cleanup efforts. Fishing related gear, balloons and plastic bags were estimated to pose the greatest entanglement risk to marine fauna. In contrast, experts identified a broader suite of items of concern for ingestion, with plastic bags and plastic utensils ranked as the greatest threats. Entanglement and ingestion affected a similar range of taxa, although entanglement was rated as slightly worse because it is more likely to be lethal. Contamination was scored the lowest in terms of impact, affecting a smaller portion of the taxa and being rated as having solely non-lethal impacts. This work points towards a number of opportunities both for policy-based and consumer-driven changes in plastics use that could have demonstrable affects for a range of ecologically important taxa that serve as indicators of marine ecosystem health. The probability of green (*Chelonia mydas*) and leatherback turtles (*Dermochelys coriacea*) ingesting litter increased significantly over time, and plastic was the most commonly ingested type of litter. Turtles in nearly all regions studied ingest litter, but the probability of ingestion was not related to modelled litter densities. Furthermore, smaller, oceanic-stage turtles were more likely to ingest litter than coastal foragers, whereas carnivorous species were less likely to ingest litter than herbivores or gelatinovores. Results indicate oceanic leatherback turtles and green turtles are at the greatest risk of both lethal and sublethal effects from ingested marine litter. Using models to visualize how turtles "see" the plastic they ingest, they found strong support for the hypothesis that turtles ingest plastic because of its resemblance to a typical prey item, jellyfish. They also ate fewer blue items, suggesting that such items may be less conspicuous against the background of open water where they forage (Schuyler et al., 2013). Wilcox et al. (2014) examined the threat ghost nets pose to marine turtles and assessed whether nets associated with particular fisheries are linked with turtle entanglement by analysing the capture rates of turtles and potential source fisheries from nearly 9000 nets found on Australia's northern coast. Nets with relatively larger mesh and smaller twine sizes (e.g., pelagic drift nets) had the highest probability of entanglement for marine turtles. Net size was important; larger nets appeared to attract turtles, which further increased their catch rates. This shows that not only the most frequent items found in the marine environment need to be considered (top findings) but also their specific characteristics need to be assessed to predict for the risk for biological impacts.

Furthermore, more recently Schuyler et al. (2015) combined global marine plastic distributions based on ocean drifter data with sea turtle habitat maps to predict exposure levels to plastic pollution. Empirical data from necropsies of deceased animals were then utilised to assess the consequence of exposure to plastics. The authors modelled the risk (probability of litter ingestion) by incorporating exposure to litter and consequence of exposure, and included life history stage, species of sea turtle and date of stranding observation as possible additional explanatory factors. The regions of highest risk to global sea turtle populations are off of the east coasts of the USA, Australia and South Africa; the East Indian Ocean, and Southeast Asia. Model results can be used to predict the number of sea turtles globally at risk of litter ingestion. Based on currently available data, initial calculations indicate that up to 52% of sea turtles may have ingested litter. Wilcox et al. (2015) performed a similar spatial risk analysis using predicted litter distributions and ranges for 186 seabird species to model litter exposure. They adjusted the model using published data on plastic ingestion by seabirds. Eighty of 135 (59%) species with studies reported in the literature between 1962 and 2012 had ingested plastic, and, within those studies, on average 29% of individuals had plastic in their gut. Standardizing the data for time and species, they estimated the ingestion rate would reach 90% of individuals if these studies were conducted today. Using these results from the literature, they tuned their risk model and were able to capture 71% of the variation in plastic ingestion based on a model including exposure, time, study method, and body size. They used this tuned model to predict risk across seabird species at the global scale. The highest area of expected impact occurs at the Southern Ocean boundary in the Tasman Sea between Australia and New Zealand, which contrasts with previous work identifying this area as having low anthropogenic pressures and concentrations of marine debris. They predict that plastics ingestion is increasing in seabirds, that it will reach 99% of all species by 2050, and that improved effective waste management can reduce this threat (Wilcox et al., 2015).

4.4 Risk assessment and management of marine litter for decision-makers

Risk management is a tool for decision-makers to translate scientific findings into policy or legislative measures. The above outlined findings form the basis of a set of instruments that help to identify priority actions with a view to the complex sources, pathways and consequences of marine litter. The presented scientific evidence presented is the result of a scientific evaluation, the risk assessment, which concluded that marine litter has adverse consequences and risks and according to which a selection of measures can be made (see also: UNEP, 2016). Whereas there is a broad range of methodologies and approaches towards the precise content and understanding approach of risk assessment, this specific section will present the understanding of risk, risk assessment and the application of the precautionary principle in the EU.

Understanding the risks and uncertainties with regard to the harm of marine litter is closely associated with the precautionary principle. Whereas the precautionary principle in EU law is not further defined, it is stipulated in Art.191 Treaty on the Functioning of the European Union. It outlines that the Union policy on environment shall be based on the precautionary principle. With a view to the missing definition in EU primary law, the European Commission has published a Communication on the precautionary principle (European Commission, 2000). Even though the Communication is not legally binding, it nevertheless presents the fundamental approach used by the European Commission with regard to this subject. Accordingly, the precautionary principle may only be invoked when three preliminary conditions are met: identification of potentially adverse effects, the evaluation of the scientific data available and the extent of scientific uncertainty (European Commission, 2000). Therefore, the European Commission underlines its understanding of the precautionary principle as belonging in the general framework of risk analysis (European Commission, 2000). The subsequent risk management measures should, according to the European Commission, be based on the following principles:

- proportionality
- non-discrimination
- consistency
- examination of the benefits and costs of action or lack of inaction
- examination of scientific evidence

In management of risks, the threshold of harm or acceptability of a polluting substance, in this case marine litter, stands central. According to Descriptor 10 of the MSFD, Good Environmental Status (GES) is achieved when "marine litter does not cause harm to the coastal and marine environment." Therefore, a very low threshold of harm or acceptability is determined through this objective (Stöfen-O'Brien, 2015). This triggers the application of precautionary measures to address the manifold consequences of marine litter.

As a consequence, the set of potential measures are broad so as to achieve or maintain GES for Descriptor 10 MSFD. Measures to be applied cover enforcement and compliance, the introduction of best environmental practise, best available techniques, awareness and education, regulatory measures and others (UNEP, 2016). This is reflected in the various measures as established under the programme of measures of the MSFD or the Regional Action Plans on Marine Litter in the different European seas. The collected evidence in this report can be regarded as a further supporting step to define harm and to provide an evidence base for the various actions needed to be implemented by decision-makers.

The overview on impacts above clearly indicates that reduction of both inputs and existing amounts of marine litter necessitates a considerable effort, sectors and sources that cannot be addressed by a single measure and organization. In addition the impacts of marine litter often occur at great distances from the points of introduction of waste into the marine environment. Tight collaboration among countries and regional as well as global organizations and initiatives is therefore needed.

The existing Regional Action Plans on Marine Litter (RAPs ML) under OSPAR, the Barcelona Convention and HELCOM deal with a comprehensive set of actions by targeting the major sea-based and land-based sources and top findings in the marine environment. Whereas prevention measures including education and outreach are key to the plans, removal actions for the different marine and river compartments have also been formulated, table 10 shows key issues addressed by the OSPAR RAP ML.

OSPAR Regional Action Plan for the North-East Atlantic	
Field of action	**Key issues**
Actions to combat sea-based sources	• Harmonized/improved system for Port Reception Facilities (including deliverance of a cost recovery system that ensures the maximum amount of MARPOL Annex V ship generated waste is delivered to ports) • Enforcement of international legislation/regulation regarding all sectors (e.g. through application of best practise in relation to inspections for MARPOL Annex V ship generated waste) • Incentives for responsible behaviour/disincentives for littering (including options to address key waste items from fishing industry) • Development of best practice in relation to waste from fishing industry (addressing relevant aspects like dolly rope, waste management on board and in harbours, operational losses/net cuttings) • Penalties/fines for littering at sea
Actions to combat land-based sources	• Identification and development of best environmental practice for waste prevention and management • Reduction of sewage and storm water related waste, including micro particles • Incentives for responsible behaviour/disincentives for littering (e.g. for reduction of single use items) • Elimination, change or adaption of products for environmental benefit (e.g. phase out the use of micro plastics in industrial applications, proposals for alternative materials to replace expanded polystyrene etc.) • Development of sustainable packaging e.g. through design improvements • Zero pellet loss along the whole plastics manufacturing chain from production to transport
Removal actions	• Application and enhancement of Fishing for Litter activities • Cleaning of environmental compartments (beaches, riverbanks, pelagic and surface sea areas, ports and inland waterways) with environmental friendly technologies and methods • Reduction of abandoned, lost and otherwise discarded fishing gear (ALDFG) including identification of accumulations of ghost nets • Identification and mapping of floating litter hotspots and hot spot areas of

OSPAR Regional Action Plan for the North-East Atlantic	
Field of action	**Key issues**
	snagging sites or historic dumping grounds
Education and outreach actions	• Database on good practise examples of marine litter measures and initiatives shared with other Regional Seas Conventions • Communication strategies to link Regional Action Plan with national initiatives/measures • Information sheets and education tools, e.g. for relevant sectors such as professional seafarers and fishermen

Table 10: Key issues, which are addressed by the OSPAR Regional Action Plan for the North-East Atlantic

Implementation of the RAPs ML is ongoing and some improvements are already visible (e.g. phase out the use of microplastic particles in products, wide application of passive fishing for litter schemes etc.). However, delaying of actions can be observed as well, often caused by the lack of sufficient funding to support the plans. The RAPs ML are instruments for efficient and effective horizontal multi stakeholder involvement. They address the major action fields where improvement is needed. By considering the implications for the marine environment as the ultimate sink for litter they add weight to existing sectoral approaches of other regimes and legal frameworks. The fact that they are implemented in parallel and address related topics represents an opportunity that should not be "wasted".

5. Conclusions

5.1 Harm to biota

5.1.1 General

- The numbers of animals affected from negative interactions with marine litter and the associated suffering that affects animal welfare in combination with the extent of encounters which in some represent a substantial proportion of a population, clearly show, that reductions in further input and of existing amounts of marine litter are urgently needed.
- The relative importance of plastic as a solid environmental contaminant is likely to increase over time. Even if the introduction of large items of litter into the marine environment ceases, the abundance of microplastics will continue to increase because of the fragmentation of larger plastic items (legacy items). So what we do today will strongly influence future quantities of micro and potentially nano-particles.
- With regard to the quality of evidence it can be concluded, that the monitoring of impacts on biota is challenging, but there is clear evidence of harm to individuals and to a lesser extent assemblages of organisms and populations of some species. There is evidence that increasing numbers of species are experiencing encounters with marine litter with manifold consequences.

5.1.2 Entanglement

- There is undeniable evidence of harm from entanglement especially for species of birds, mammals, fish and all turtles.
- To consider harm at the individual level in addition to estimating the numbers of individuals affected in relation to population size is likely to offer the most feasible and representative conclusions about entanglement.
- There is some evidence of population level impacts from entanglement especially for sea birds, seals and fish.
- Entanglement depends on body size, shape and behaviour of the animal concerned as well as the type of litter it encounters and the level of litter pollution in the environment in which the animals lives.
- There is clear evidence of the negative impact of abandoned, lost or otherwise discarded fishing gear (ALDFG) on marine species including commercially important fish.
- Harm from entanglement is easier to observe and therefore to quantify than harm resulting from ingestion. Hence the extent of harm caused by ingestion is likely to be underestimated.

5.1.3 Ingestion

- There is clear evidence that a substantial number of marine species ingest plastic litter often associated with lethal and sub-lethal impacts.
- For some species, including mammals, birds, fishes and invertebrates there is also clear evidence that in some populations a large proportion of individuals contain plastic litter.
- There is experimental evidence of negative physical/mechanical impacts from ingestion of plastic on the condition, reproductive capacity and survival of individual marine organisms. However, the evidence is restricted to laboratory experiments with organisms from lower trophic levels.
- The combination of these findings implies evidence of harm in natural populations, but quantifying the extent of this harm would be extremely challenging.
- The extent of harm caused by ingestion is likely to be underestimated, because necropsies have to be carried out.

5.1.4 Chemical transfer

- Some plastics are known to contain chemical additives that are potentially harmful to wildlife.
- As has been shown for other particulates it is certain that plastics can sorb and concentrate chemicals from seawater.
- There is clear evidence that plastic can transfer chemicals contaminants to wildlife. However, there is considerable uncertainty about the relative importance of plastic, as a pathway facilitating the transport of chemicals to biota, compared to other pathways such as from water or natural diet.

5.1.5 Marine Litter as a vector for transport of biota

- Representative species of bacteria (including pathogens), algae, unicellular organisms, and most invertebrates groups have been demonstrated to settle on debris, floating or on the sea floor (so-called rafting).
- Characteristics of litter items make them similar or different to natural floating debris in facilitating transport, and dispersion and possible colonization.
- To date it is hard to quantify the relative importance of rafting on anthropogenic compared to natural debris.
- Litter pollution has substantially increased the number of objects to which organisms can attach themselves.
- Plastic items have generally longer lifespans in the marine environment than some natural debris and potentially could be moved by ocean currents over longer distances for longer timespans.

5.1.6 Marine litter altering/modifying assemblages of species

- The presence of marine litter can modify natural habitats, transport chemical contaminants and invasive species.
- It is certain that marine litter affects individuals. It can also modify marine assemblages as a consequence of either smothering, direct physical damage or provision of a new habitat.
- Evidence of effects comes from localized studies. There is a poor understanding of how this data could be extrapolated to larger spatial scales. It is important to acknowledge that decisions on policy measures will likely need to be made in the absence of such information.

5.1.6 Levels of biological organization affected

- There is direct evidence that there are harmful effects of marine litter on individual organisms of many species.
- Linking evidence of the substantial numbers of individuals affected by marine plastic litter to negative effects on populations is challenging and not possible to date for most affected species. It is important to recognize that the policy decisions on measures to reduce input of marine litter will likely need to be based on other evidence of harm documented herein.
- There is evidence that marine litter negatively affects population of some species.
- There is evidence from small scale studies that marine litter can modify marine assemblages.
- There is a growing evidence that marine litter, in combination with other anthropogenic stressors, represents a substantial additional challenge to marine biodiversity.
- As with many other anthropogenic stressors quantifying the effects of marine litter in isolation on biodiversity is often extremely challenging.
- Some examples for linkages among levels of biological organization for effects of litter in organisms are available. In the future models and experimental settings must be constructed and designed in a way to determine whether populations are declining because of litter and if so which parts of the life cycle are affected.

5.1.7 Animal welfare

- Marine litter causes unnecessary and avoidable suffering to marine animals.
- A concerted effort is needed to set up a comprehensive species and litter-type specific dataset to enable comparative scoring of welfare impacts.

5.2 Socioeconomic harm

- From evidence available it becomes clear that marine litter has negative social and economic impacts including significant costs to the sectors affected, reducing the ecosystem services and compromising perceived benefits.
- While there are data gaps, it is expected that the costs of action are generally significantly less than the costs of inaction.
- Designing products to ensure they are compatible with recycling, followed by appropriate collection and recycling will simultaneously reduce the quantity of waste in managed systems and in the environment.
- Moving toward a more circular economy will reduce waste, including litter, and simultaneously increase resource efficacy.
- Marine litter including nets and ropes, pieces of glass, metal fragments and discarded medical waste may be harmful to humans.
- Marine litter can act as a vehicle for the transport of pathogens but the relative importance of this pathway from a human health perspective is uncertain.
- Microplastics are present in commercially important species of fish and shellfish. However it is not certain if there is any risk associated with human consumption.
- A range of potentially harmful chemical additives are used in some plastic items. However, it is not clear whether the presence of these items as marine litter presents a human exposure pathway.

5.3 Risk assessment for marine litter

- Risk assessment can help to identify priority actions with a view to the complex sources, pathways and consequences of marine litter.
- Understanding the risks and uncertainties with regard to the harm caused marine litter is closely associated with the precautionary principle.
- The collected evidence in this report can be regarded as a supporting step to define harm and to provide an evidence base for the various actions needed to be implemented by decision-makers, which are inter alia defined in the Regional Action Plans on Marine Litter.

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List of abbreviations and definitions

ALDFG	Abandoned, lost or discarded fishing gear
CBD	Convention on Biological Diversity
GES	Good Environmental Status
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Commission
HOLAS	HELCOM Holistic Assessment of the ecosystem health of the Baltic Sea
IUCN	International Union for the Conservation of Nature
MS	Member States
MSFD	Marine Strategy Framework Directive
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PBDEs	Polybrominated diphenyl ethers (flame retardants)
PCBs	Polychlorinated biphenyls
POPs	Persistent organic pollutants
PVC	Polyvinyl chloride (plastic polymer)
RSC	Regional Seas Conventions
TG ML	MSFD GES Technical Group on Marine Litter
UNEP	United Nations Environment Programme
WTP	Willingness to Pay

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Annex I

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G1	1	PL05	4/6-pack yokes, six-pack rings	Artificial polymer materials	x
G2		PL07	Bags	Artificial polymer materials	x
G3	2	PL07	Shopping Bags incl. pieces	Artificial polymer materials	x
G4	3	PL07	Small plastic bags, *e.g.* freezer bags incl. pieces	Artificial polymer materials	x
G5	112		Plastic bag collective role; what remains from rip-off plastic bags	Artificial polymer materials	
G6	4	PL02	Bottles	Artificial polymer materials	
G7	4	PL02	Drink bottles <=0.5l	Artificial polymer materials	
G8	4	PL02	Drink bottles >0.5l	Artificial polymer materials	
G9	5	PL02	Cleaner bottles & containers	Artificial polymer materials	
G10	6	PL06	Food containers incl. fast food containers	Artificial polymer materials	
G11	7	PL02	Beach use related cosmetic bottles and containers, *e.g.* Sunblocks	Artificial polymer materials	
G12	7	PL02	Other cosmetics bottles & containers	Artificial polymer materials	
G13	12	PL02	Other bottles & containers (drums)	Artificial polymer materials	
G14	8		Engine oil bottles & containers <50 cm	Artificial polymer materials	
G15	9	PL03	Engine oil bottles & containers >50 cm	Artificial polymer materials	
G16	10	PL03	Jerry cans (square plastic containers with handle)	Artificial polymer materials	
G17	11		Injection gun containers	Artificial polymer materials	
G18	13	PL13	Crates and containers / baskets	Artificial polymer materials	
G19	14		Car parts	Artificial polymer materials	
G20		PL01	Plastic caps and lids	Artificial polymer materials	
G21	15	PL01	Plastic caps/lids drinks	Artificial polymer materials	
G22	15	PL01	Plastic caps/lids chemicals, detergents (non-food)	Artificial polymer materials	
G23	15	PL01	Plastic caps/lids unidentified	Artificial polymer materials	
G24	15	PL01	Plastic rings from bottle caps/lids	Artificial polymer materials	X
G25			Tobacco pouches / plastic cigarette box packaging	Artificial polymer materials	
G26	16	PL10	Cigarette lighters	Artificial polymer materials	X
G27	64	PL11	Cigarette butts and filters	Artificial polymer materials	
G28	17		Pens and pen lids	Artificial polymer materials	
G29	18		Combs/hair brushes/sunglasses	Artificial polymer materials	
G30	19		Crisps packets/sweets wrappers	Artificial polymer materials	
G31	19		Lolly sticks	Artificial polymer materials	
G32	20	PL08	Toys and party poppers	Artificial polymer materials	X

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G33	21	PL06	Cups and cup lids	Artificial polymer materials	X
G34	22	PL04	Cutlery and trays	Artificial polymer materials	
G35	22	PL04	Straws and stirrers	Artificial polymer materials	
G36	23		Fertiliser/animal feed bags	Artificial polymer materials	X
G37	24	PL15	Mesh vegetable bags	Artificial polymer materials	X
G38			Cover / packaging	Artificial polymer materials	
G39		PL09	Gloves	Artificial polymer materials	
G40	25	PL09	Gloves (washing up)	Artificial polymer materials	
G41	113	RB03	Gloves (industrial/professional rubber gloves)	Artificial polymer materials	
G42	26	PL17	Crab/lobster pots and tops	Artificial polymer materials	X
G43	114		Tags (fishing and industry)	Artificial polymer materials	
G44	27	PL17	Octopus pots	Artificial polymer materials	X
G45	28	PL15	Mussels nets, Oyster nets	Artificial polymer materials	X
G46	29		Oyster trays (round from oyster cultures)	Artificial polymer materials	X
G47	30		Plastic sheeting from mussel culture (Tahitians)	Artificial polymer materials	
G48			Synthetic rope	Artificial polymer materials	X
G49	31	PL19	Rope (diameter more than 1cm)	Artificial polymer materials	X
G50	32	PL19	String and cord (diameter less than 1cm)	Artificial polymer materials	X
G51		PL20	Fishing net	Artificial polymer materials	X
G52		PL20	Nets and pieces of net	Artificial polymer materials	X
G53	115	PL20	Nets and pieces of net < 50 cm	Artificial polymer materials	X
G54	116	PL20	Nets and pieces of net > 50 cm	Artificial polymer materials	X
G55		PL18	Fishing line (entangled)	Artificial polymer materials	X
G56	33	PL20	Tangled nets/cord	Artificial polymer materials	X
G57	34	PL17	Fish boxes - plastic	Artificial polymer materials	
G58	34	PL17	Fish boxes - expanded polystyrene	Artificial polymer materials	
G59	35	PL18	Fishing line/monofilament (angling)	Artificial polymer materials	X
G60	36	PL17	Light sticks (tubes with fluid) incl. packaging	Artificial polymer materials	
G61			Other fishing related	Artificial polymer materials	X
G62	37	PL14	Floats for fishing nets	Artificial polymer materials	X
G63	37	PL14	Buoys	Artificial polymer materials	
G64			Fenders	Artificial polymer materials	
G65	38	PL03	Buckets	Artificial polymer materials	
G66	39	PL21	Strapping bands	Artificial polymer materials	X
G67	40	PL16	Sheets, industrial packaging, plastic sheeting	Artificial polymer materials	

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G68	41	PL22	Fibre glass/fragments	Artificial polymer materials	
G69	42		Hard hats/Helmets	Artificial polymer materials	
G70	43		Shotgun cartridges	Artificial polymer materials	
G71	44	CL01	Shoes/sandals	Artificial polymer materials	
G72			Traffic cones	Artificial polymer materials	
G73	45	FP01	Foam sponge	Artificial polymer materials	
G74			Foam packaging/insulation/polyurethane	Artificial polymer materials	
G75	117		Plastic/polystyrene pieces 0 - 2.5 cm	Artificial polymer materials	
G76	46		Plastic/polystyrene pieces 2.5 cm > < 50cm	Artificial polymer materials	
G77	47		Plastic/polystyrene pieces > 50 cm	Artificial polymer materials	
G78			Plastic pieces 0 - 2.5 cm	Artificial polymer materials	
G79			Plastic pieces 2.5 cm > < 50cm	Artificial polymer materials	
G80			Plastic pieces > 50 cm	Artificial polymer materials	
G81			Polystyrene pieces 0 - 2.5 cm	Artificial polymer materials	
G82			Polystyrene pieces 2.5 cm > < 50cm	Artificial polymer materials	
G83			Polystyrene pieces > 50 cm	Artificial polymer materials	
G84			CD, CD-box	Artificial polymer materials	
G85			Salt packaging	Artificial polymer materials	
G86			Fin trees (from fins for scuba diving)	Artificial polymer materials	
G87			Masking tape	Artificial polymer materials	
G88			Telephone (incl. parts)	Artificial polymer materials	
G89			Plastic construction waste	Artificial polymer materials	
G90			Plastic flower pots	Artificial polymer materials	
G91			Biomass holder from sewage treatment plants	Artificial polymer materials	
G92			Bait containers/packaging	Artificial polymer materials	
G93			Cable ties	Artificial polymer materials	X
G94			Table cloth	Artificial polymer materials	
G95	98	OT02	Cotton bud sticks	Artificial polymer materials	
G96	99	OT02	Sanitary towels/panty liners/backing strips	Artificial polymer materials	
G97	101	OT02	Toilet fresheners	Artificial polymer materials	
G98		OT02	Diapers/nappies	Artificial polymer materials	
G99	104	PL12	Syringes/needles	Artificial polymer materials	
G100	103		Medical/Pharmaceuticals containers/tubes	Artificial polymer materials	
G101	121		Dog faeces bag	Artificial polymer materials	X
G102		RB02	Flip-flops	Artificial polymer materials	
G103			Plastic fragments rounded <5mm	Artificial polymer materials	

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G104			Plastic fragments subrounded <5mm	Artificial polymer materials	
G105			Plastic fragments subangular <5mm	Artificial polymer materials	
G106			Plastic fragments angular <5mm	Artificial polymer materials	
G107			cylindrical pellets <5mm	Artificial polymer materials	
G108			disks pellets <5mm	Artificial polymer materials	
G109			flat pellets <5mm	Artificial polymer materials	
G110			ovoid pellets <5mm	Artificial polymer materials	
G111			spheruloids pellets <5mm	Artificial polymer materials	
G112		PL23	Industrial pellets	Artificial polymer materials	
G113			Filament <5mm	Artificial polymer materials	
G114			Films <5mm	Artificial polymer materials	
G115			Foamed plastic <5mm	Artificial polymer materials	
G116			Granules <5mm	Artificial polymer materials	
G117			Styrofoam <5mm	Artificial polymer materials	
G118			Small industrial spheres (<5mm)	Artificial polymer materials	
G119			Sheet like user plastic (>1mm)	Artificial polymer materials	
G120			Threadlike user plastic (>1mm)	Artificial polymer materials	
G121			Foamed user plastic (>1mm)	Artificial polymer materials	
G122			Plastic fragments (>1mm)	Artificial polymer materials	
G123			Polyurethane granules <5mm	Artificial polymer materials	
G124	48	PL24	Other plastic/polystyrene items (identifiable)	Artificial polymer materials	
G125	49	RB01	Balloons and balloon sticks	Rubber	
G126		RB01	Balls	Rubber	
G127	50		Rubber boots	Rubber	
G128	52	RB04	Tyres and belts	Rubber	X
G129		RB05	Inner-tubes and rubber sheet	Rubber	X
G130			Wheels	Rubber	X
G131		RB06	Rubber bands (small, for kitchen/household/post use)	Rubber	X
G132			Bobbins (fishing)	Rubber	
G133	97	RB07	Condoms (incl. packaging)	Rubber	
G134	53	RB08	Other rubber pieces	Rubber	
G135		CL01	Clothing (clothes, shoes)	Cloth/textile	
G136		CL01	Shoes	Cloth/textile	
G137	54	CL01	Clothing / rags (clothing, hats, towels)	Cloth/textile	X
G138	57	CL01	Shoes and sandals (*e.g.* Leather, cloth)	Cloth/textile	
G139		CL02	Backpacks & bags	Cloth/textile	

Master List of Categories of Litter Items					
TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G140	56	CL03	Sacking (hessian)	Cloth/textile	
G141	55	CL05	Carpet & Furnishing	Cloth/textile	
G142		CL04	Rope, string and nets	Cloth/textile	X
G143		CL03	Sails, canvas	Cloth/textile	
G144	100	OT02	Tampons and tampon applicators	Cloth/textile	
G145	59	CL06	Other textiles (incl. rags)	Cloth/textile	
G146			Paper/Cardboard	Paper/Cardboard	
G147	60		Paper bags	Paper/Cardboard	
G148	61	PC02	Cardboard (boxes & fragments)	Paper/Cardboard	
G149		PC03	Paper packaging	Paper/Cardboard	
G150	118	PC03	Cartons/Tetrapack Milk	Paper/Cardboard	
G151	62	PC03	Cartons/Tetrapack (others)	Paper/Cardboard	
G152	63	PC03	Cigarette packets	Paper/Cardboard	
G153	65	PC03	Cups, food trays, food wrappers, drink containers	Paper/Cardboard	
G154	66	PC01	Newspapers & magazines	Paper/Cardboard	
G155		PC04	Tubes for fireworks	Paper/Cardboard	
G156			Paper fragments	Paper/Cardboard	
G157			Paper	Paper/Cardboard	
G158	67	PC05	Other paper items	Paper/Cardboard	
G159	68	WD01	Corks	Processed/worked wood	
G160	69	WD04	Pallets	Processed/worked wood	
G161	69	WD04	Processed timber	Processed/worked wood	
G162	70	WD04	Crates	Processed/worked wood	
G163	71	WD02	Crab/lobster pots	Processed/worked wood	X
G164	119		Fish boxes	Processed/worked wood	
G165	72	WD03	Ice-cream sticks, chip forks, chopsticks, toothpicks	Processed/worked wood	
G166	73		Paint brushes	Processed/worked wood	
G167		WD05	Matches & fireworks	Processed/worked wood	
G168			Wood boards	Processed/worked wood	
G169			Beams / Dunnage	Processed/worked wood	
G170			Wood (processed)	Processed/worked wood	
G171	74	WD06	Other wood < 50 cm	Processed/worked wood	
G172	75	WD06	Other wood > 50 cm	Processed/worked wood	
G173		WD06	Other (specify)	Processed/worked wood	
G174	76		Aerosol/Spray cans industry	Metal	

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G175	78	ME03	Cans (beverage)	Metal	
G176	82	ME04	Cans (food)	Metal	
G177	81	ME06	Foil wrappers, aluminium foil	Metal	
G178	77	ME02	Bottle caps, lids & pull tabs	Metal	
G179	120		Disposable BBQ's	Metal	
G180	79	ME10	Appliances (refrigerators, washers, etc.)	Metal	
G181		ME01	Tableware (plates, cups & cutlery)	Metal	
G182	80	ME07	Fishing related (weights, sinkers, lures, hooks)	Metal	X
G183		ME07	Fish hook remains	Metal	
G184	87	ME07	Lobster/crab pots	Metal	X
G185			Middle size containers	Metal	
G186	83	ME10	Industrial scrap	Metal	
G187	84	ME05	Drums, *e.g.* oil	Metal	
G188		ME04	Other cans (< 4 L)	Metal	
G189		ME05	Gas bottles, drums & buckets (> 4 L)	Metal	
G190	86	ME05	Paint tins	Metal	
G191	88	ME09	Wire, wire mesh, barbed wire	Metal	X
G192		ME05	Barrels	Metal	
G193			Car parts / batteries	Metal	
G194			Cables	Metal	X
G195		OT04	Household Batteries	Metal	
G196			Large metallic objects	Metal	
G197			Other (metal)	Metal	
G198	89	ME10	Other metal pieces < 50 cm	Metal	
G199	90	ME10	Other metal pieces > 50 cm	Metal	
G200	91	GC02	Bottles incl. pieces	Glass/ceramics	X
G201		GC02	Jars incl. pieces	Glass/ceramics	
G202	92	GC04	Light bulbs	Glass/ceramics	X
G203		GC03	Tableware (plates & cups)	Glass/ceramics	
G204	94	GC01	Construction material (brick, cement, pipes)	Glass/ceramics	
G205	92	GC05	Fluorescent light tubes	Glass/ceramics	X
G206		GC06	Glass buoys	Glass/ceramics	
G207	95		Octopus pots	Glass/ceramics	
G208		GC07	Glass or ceramic fragments >2.5cm	Glass/ceramics	
G209			Large glass objects (specify)	Glass/ceramics	
G210	96	GC08	Other glass items	Glass/ceramics	X

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Entanglement
G211	105	OT05	Other medical items (swabs, bandaging, adhesive plaster etc.)	unidentified	
G212			Slack / Coal		
G213	181, 109, 110	OT01	Paraffin/Wax	Chemicals	
G214			Oil/Tar	Chemicals	
G215			Food waste (galley waste)	Food waste	
G216			various rubbish (worked wood, metal parts)	undefined	
G217			Other (glass, metal, tar) <5mm	unidentified	

Annex II

Several key definitions pertaining to environmental risk assessment and management are detailed below (taken from Bradbury et al., 2004):

Hazard: An event or agent (biological, chemical or physical) that may lead to harm or cause adverse effects. Hazards can also have magnitude – some of which might be acceptable and some of which might not. For the purposes of risk assessment, the source-strength of the hazard can be equated to pressure.

Hazard identification/characterisation: The identification of which types of physical or ecological receptors could be affected by a given hazard and the extent to which these receptors might be affected if exposed at a given level (e.g. the dose response relationship). It may be convenient and sensible to express the magnitude of the hazard as a single effect threshold.

Risk: The potential consequence(s) of a hazard combined with its likelihood (or probability) of occurrence. There are several ways of assessing or quantifying risk depending on the purpose of the assessment and the data available.

Risk assessment: The formal process of evaluating risk i.e. the product of the likelihood of a hazard causing harm to receptors and the magnitude of the resulting consequence(s).

Risk management: The process of acting to minimise risks by preventing, containing or controlling emission or protecting receptors. Risk management often works by putting in place physical or procedural barriers to reduce the probability of a hazardous event occurring.

Risk-based decision-making: The process of choice based on identifying the likely consequences of different options and selecting the best course of action related to minimising and managing environmental risks.

Exposure assessment: the determination of which types of physical or ecological receptors are likely to be exposed at a site, the pathways by which exposure may occur, and the degree of exposure (magnitude and frequency).

Source: the causal factor for hazard(s). In simple terms the source (e.g. pile driving, dredging) is derived from an activity (e.g. installation of an offshore wind farm, port operation).

Pathway: the mechanism by which a receptor is exposed to a hazard (e.g., hydrodynamic regime, ingestion of contaminated water, ingestion of contaminated soil or food, direct contact with contaminated water or soil). Relevant characteristics of the pathway can be defined in the assessment (e.g. distance from source to receptor and likely rate of dissipation of the hazard en route) which can affect the magnitude of the hazard at the receptor and hence the risk.

Receptors: physical (beaches, sandbanks, mudflats) or ecological (e.g. fish, birds, mammals, plants) entities which are sensitive to the hazards under investigation. In other words, entities which could be affected if exposed to the hazard at a deleterious level.

S-P-R: a conceptual model describing the relationships between the source (S) of a hazard, the pathways (P) by which exposure might occur, and the environmental receptors (R) that could be harmed.

Pressure: the mechanism by which human activities exert an effect on ecosystem components (e.g. habitats and species). They can be physical (e.g. sediment deposition), chemical (e.g. introduction of contaminants) or biological (e.g. introduction of microbial pathogens). For the purposes of risk assessment pressure can be equated to hazard.
Activity: the parameter providing the source for hazards.

Effects or Impacts: are an estimation of the receptors response to the hazard(s) to which they are exposed. Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment, uses both the terms „effect“ and „impact“ interchangeably. The selection criteria for determining the characteristics of potential impact / significant effects are listed in the Directive as: a) the extent of the impact (geographical area and size of the affected population); b) the trans-frontier nature of the impact; c)the magnitude and complexity of the impact; (d) the probability of the impact; (e) the duration, frequency and reversibility of the impact.

Probability: The likelihood that a given event will occur. May be expressed as a number describing the likelihood that a specific event will occur, i.e. the ratio of the number of actual (or expected) occurrences to the number of possible occurrences.

Effect level: is the point(s) above which it is judged that an effect will be produced or a response elicited. Effect levels are generally established from empirical evidence, (e.g. observed effects of underwater noise at given levels) but may also use established criteria (e.g. Action Levels). Effect levels are also sometimes described as "thresholds".

Stakeholders: parties who are interested in, or affected by, an issue or situation.

Uncertainty: The degree to which knowledge is limited (e.g. about the sensitivity of a receptor to a hazard or the factors which influence exposure). Uncertainty originates from randomness (aleatory uncertainty) and incomplete knowledge (epistemic uncertainty).

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